FINAL REPORT

Field Testing Pulsed Power Inverters in Welding Operations to Control Heavy Metal Emissions

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14. ABSTRACT

This study evaluated the emission reduction of hexavalent chromium , nickel, manganese and other metals generated during welding operations while using pulsed power inverter (PPI) technology. Particle size distribution and metal sp4ecies differentiation within each particle size was examined using gravimetric and laboratory analyses. Emissions from ozone, carbon monoxide and nitrogen oxides were evaluated using real-time monitoring. Emissions for operations using PPI technology were compared with welding processes, typically mild steel, used during maintenance operations at four DOD facilities. The goal was to confirm manufacturer's claims of significant metals reduction while using PPI Technology. There may be an increase in productivity and, once acclimated, welders accepted the new technology. However, the study did not find a significant reduction in weld fume constituent (metals) emissions on the four DOD operations studied. Welding material quality using PPI was similar to the currently used or conventional gas metal and metal arc (GMAW) and flux core arc welding (FCAW) operations.

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ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
ANAD	Anniston Army Depot, Anniston, AL
AWS	American Welding Society
CEM	Continuous Emission Monitor
CFR	Code of Federal Regulations
CI	Cascade impactor
CVN	Charpy v-notch strength of a weld specimen
DOD	Department of Defense
EPA	United States Environmental Protection Agency
FCAW	Flux cored arc welding
FR	Federal Register
GMAW	Gas metal arc welding
HAP	EPA Hazardous Air Pollutant (40 CFR 63)
HEPA	High efficiency particulate air filter
HY	High yield (steel type 80 kpsi and 100 kpsi)
IC	ion chromatography
ICP-AES	Inductively Coupled Argon Plasma, Atomic Emission Spectroscopy
IH	Industrial hygiene
LOD	limit of detection
MCE	Methyl cellulose ester (filter material)
MCLB	Marine Corps Logistics Base, Albany, GA
NESHAP	National Emission Standards for Hazardous Air Pollutants
NEHC	Naval Environmental Health Center
NIOSH	National Institute for Occupational Safety and Health
NSWCCD	Naval Surface Warfare Center Carderock Division
OS	Ordinary Steel
OSHA	Occupational Safety and Health Administration
OSH&E	Occupational Safety, Health, and Environment
PEL	Permissible Exposure Limit (from OSHA)
PM2.5	Particulate Matter, less than 2.5 micron diameter
PPE	Personal Protective Equipment
ppbv	Parts per Billion by Volume

PPI	Pulsed Power Inverter – the demonstrated power source
PSNSY	Puget Sound Naval Shipyard, Bremerton, WA
PVC	Polyvinylchloride (Filter material and ductwork)
REL	Recommended Exposure Limits (from NIOSH)
SIMA	Ship Intermediate Maintenance Activity, San Diego, CA
SMAW	Shielded metal arc welding ("stick" welding)
SWRMC	Southwest Regional Maintenance Center, San Diego, CA (formerly SIMA)
TLV	Threshold Limit Value (from ACGIH)
TWA	Time Weighted Average (with exposure limit)
UV	Ultraviolet
WGBT	Wet Globe Bulb Temperature

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Appendix A gives contact information directly or via supervisory channels for those mentioned above

EXECUTIVE SUMMARY

Both the Occupational Safety and Health Agency (OSHA) and United States Environmental Protection Agency (USEPA) policies regulate certain fume components emitted during welding operations. Specifically, the policies of both agencies regulate hexavalent chromium (Cr^{+6}) emissions. OSHA policies regulate Cr^{+6} occupational exposures regardless of their source. USEPA policies, however, do not directly regulate hexavalent chromium emissions from welding operations, although it does regulate Cr^{+6} from other sources (e.g., electroplating operations). EPA personnel are in discussions with stakeholder regarding an expansion to include hexavalent chromium emissions from welding under the National Environmental Standards for Hazardous Air Pollutants (NESHAP) for Shipbuilding and Ship Repair Facilities (Surface Coatings). In locations where USEPA regulates fugitive emissions, it may regulate Cr^{+6} as well as other components of the fugitive emissions. Other welding emissions of potential concern to both agencies are nitrogen oxides (NO_x), carbon monoxide (CO), ozone (O_3), total particulate matter, and metals such as manganese, copper, and nickel.

Welding operations are an intrinsic part of Department of Defense (DOD) equipment maintenance operations; hence DOD personnel are seeking to reduce emissions from welding. The demonstration described in this report compares emissions from Pulsed Power Inverter (PPI) power sources to the power sources used during existing welding processes, typically flux core arc welding (FCAW) and shielded metal arc welding (SMAW). PPI technology is reported to produce lower emissions compared to conventional pulsed power wire welding techniques. This demonstration was performed on mild steel (<0.5% Cr), HY-80 steel (1.0-1.9% Cr), and “chrome-moly” 4130 steel (nominally 1% Cr) test plates at four DOD facilities (2 Navy, 1 Marine, and 1 Army). It should be noted that DOD equipment maintenance and repair operations do not typically weld stainless steel products in large quantities. The test plates were also evaluated for weld quality to determine if PPI provides comparable integrity compared to existing technology.

Initial laboratory tests were performed to optimize power source settings for PPI welding power equipment from several manufacturers. Using American Welding Society (AWS) test methods and the results of the initial testing, two PPI welding machines were selected for evaluation. Optimization for fume emissions did not produce quality welds required to meet the standards for tactical vehicles and ships. Generally, the manufacturer’s recommended settings were found to be a reasonable compromise between weld quality and reduced fume generation.

Field demonstrations usually consisted of a baseline week of contaminant collection using the conventional system and a week of PPI fume collection. A fume ventilation system was set up to collect a steady (i.e., constant volume) stream of fumes from each welding event. Particulate matter was withdrawn isokinetically from the ventilation system ductwork during welding operations (using a modified EPA Method 5 sampling train), and separated into nine particulate size ranges using a 9-stage Cascade Impactor (CI) in the fume sampling train. Each impactor stage was weighed to determine total particulate distribution. The contents of each stage were analyzed for 20 metals, including total Cr and Cr^{+6}. In addition to particulate/metal sampling, real-time continuous emissions monitoring (CEM) was conducted for NO_x, CO, and O_3, by withdrawing a continuous gas stream from the ventilation system ductwork.

Industrial Hygiene (IH) engineering (area only) samples were also collected, using OSHA Method 215 and the National Institute for Occupational Safety and Health (NIOSH) Method 7300 and analyzed for Cr^{+6} and total metal content, respectively. IH samples were sampled continuously throughout each day of welding operations, both near the welder (about two-feet away), and at a more remote location (about ten-feet away). The concentration of metals sampled in this demonstration were expected to be of lower concentration than typical from more representative welding operations, since the majority of the fumes generated were removed by the fume exhaust ventilation system used to collect particulate emissions. Many welding operations are performed with only natural ventilation, rather than the ventilation system used for this demonstration. This is particularly true during quick repairs and outdoor welding.

The intensity of ultraviolet (UV) emissions from the welding operations was also evaluated. This was accomplished by placing a real-time UV sensor near the welder, within line-of-sight of the welding operation.

Particle size distribution data show that emitted particle size was predominantly in the sub-micron diameter range. Typically, over 50% of the particles (by weight) were less than 0.8-micron in size. The only metals present in the welding fumes at significant concentrations (above about 5 percent) were iron, manganese, and magnesium. (Aluminum, zinc, and barium were also present, but they are believed to be an artifact of the CI substrate filter material.) Other metals that appear in the 1 – 5% range were arsenic, nickel, strontium, and copper. Total chromium appeared in the 1% range only during welding operations on chromium-molybdenum (Cr-Mo) 4130 steel at Southwest Regional Maintenance Center (SWRMC). Otherwise it was typically less than 0.1%. For almost all sampling events there was not enough Cr^{+6} in either the CI or IH samples to violate either EPA or OSHA regulations, including OSHA's recently promulgated requirement (71 FR 10100 – 28 Feb 2006) of 5.0 micrograms per cubic meter ($\mu g/m^3$) for Cr^{+6} exposure. The exception was welding 3140 Cr-Mo steel where Cr^{+6} IH emissions were significant enough that they averaged 2.59 $\mu g/m^3$, with the highest daily value being 8.60$\mu g/m^3$. Unlike the other welding sites, the SWRMC welder wore a positive air pressure {assisted} respirator (PAPR).

For most of the welding operations, O_3 emissions clearly increased to more than 100 parts per billion by volume (ppbv) compared to background concentrations (below about 30 ppbv). NO_x may also evolve during welding operations, but it is more difficult to determine quantitatively because of interferences from local fossil fuel combustion devices (e.g., trucks, fork lifts, water heaters). Some welding operations did not show significant increases in NO_x or O_3 concentrations compared to background. CO emissions do not appear to significantly increase above a background as a result of the welding operations. However, the presence of fossil fuel combustion sources, e.g. forklifts and nearby unit heaters in the test area, did result in elevated CO emissions.

There do not appear to be any obvious differences in any of the emission parameters from PPI versus conventional pulsed power sources. It appears, however, that SMAW produces a greater particulate loading per amount of welding rod used when compared to wire welding techniques, a well-known finding.

Test plates were evaluated for weld quality to determine of PPI provides comparable integrity compared to conventional power sources. The quality of PPI welds, in terms of tensile strength, yield strength, and Chevron V Notch (CVN), was equivalent to conventional pulsed power sources.

1.0 INTRODUCTION

1.1 BACKGROUND

Pulsed power welding is a conventional welding technique that has been used for years for wire welding operations. A recent modification to pulsed power welding involves the "inversion" of DC power to AC power for what is reported by equipment vendors, to give a better overall welding performance. Pulsed power inverter (PPI) technology is an improvement to gas metal arc welding (GMAW) technology. Along with improved welding performance, enhancements are advertised to reduce emissions of some welding fume components. DOD craftspeople perform welding operations at most of its facilities; and in particular, high volume welding is carried out at facilities dedicated to the major overhaul and repair of large military equipment (e.g., ships, tanks, armored personnel carriers, weapons systems, etc.). Therefore, it is beneficial to the interests of DOD to compare conventional welding power sources to pulsed power inverter (PPI) welding power sources to compare the difference in the rate of emission of fume particle sizes and metal constituents, as well as the weld quality.

1.2 OBJECTIVES OF THE DEMONSTRATION

The objectives of this demonstration project are to measure fume components and emission rates from both conventionally powered power welding and PPI power sources, to determine what differences may exist. These components are: (a) particulates and the metal oxides, of which the particulates are primarily comprised, (b) nitrogen oxides (NO_x) gases, (c) carbon monoxide (CO) gas, and (d) ozone (O_3) gas. Atmospheric emissions of these components were measured, as well as a measure of the relative exposure of these components to welding personnel. In addition, the level of ultraviolet (UV) radiation was measured. To the extent possible, these parameters were measured relative to the welding parameters performed (e.g., length of weld, amount of welding wire/rod used).

The quality and quantity of welding emissions become academic if the quality of the welding being performed is inadequate. Therefore, many of the welded test plates were also evaluated to determine their metallurgical properties (e.g., tensile strength, yield strength, toughness) (1).

1.3 REGULATORY DRIVERS

Both OSHA and EPA regulate certain components of the fumes emitted by welding operations. Specifically, both agencies regulate hexavalent chromium (Cr^{+6}) emissions in 29 Code of Federal Regulations (CFR) 1910.1026, Hexavalent Chromium, and 40 CFR, Clean Air Act, respectively.

However, USEPA regulations do not specifically regulate Cr^{+6} from welding operation point sources (as they do, for instance, from chromium electroplating). From some facilities USEPA regulates fugitive emissions (i.e., emissions from other than point sources), of which Cr^{+6} may be a component. Additionally, chromium compounds (including Cr^{+6}) are one of many USEPA-designated Hazardous Air Pollutants (HAPs). Manganese and nickel compounds are also HAPs. However, there are no specific regulations relating to HAPs with respect to welding operations. EPA personnel are in discussions with stakeholders regarding an expansion of the National Emission Standards for Hazardous Air Pollutants (NESHAP) for Shipbuilding and Ship Repair Facilities (Surface Coatings) to include hexavalent chromium emissions from welding because 2006 residual risk analyses are not reflecting EPA goals when considering surface coatings alone. In some situations, for "major" emissions sources, total HAPs from a facility must exceed 25 tons per year, or 10 tons per individual HAP before they are regulated. Welding emissions from DOD industrial facilities may contribute a fraction of those quantities.

OSHA's recently promulgated a new permissible exposure limit for Cr^{+6} exposures at 5.0 microgram per cubic meter (µg/m^3) on a time-weighted average (TWA) basis from any source. (71 FR 10100 – 28 Feb 2006) Previous OSHA requirements for "chromium metal and insoluble salts" were 1,000 µg/m^3 time-weighted-average, and for Cr^{+6} in "chromic acid and chromates" the ceiling concentration were 52 µg/m^3 - 29 CFR 1910.1000(a) & (b), Tables Z-1 & Z-2, Limits for Air Contaminants. This demonstration anticipated a reduced standard.* and used new field and laboratory analysis methodologies reflecting the more stringent regulation. (2)

Other potential welding emissions of concern to both agencies are nitrogen oxides (NO_x), carbon monoxide (CO), ozone (O_3), total particulate matter, and metals other than Cr^{+6}. USEPA standards regulate NO_x, CO, and O_3 in ambient air with specific standards, but do not generally regulate these gases from point sources except for major sources such as electric power plant boilers. Nor do USEPA regulations address specific metals in ambient air (except lead), but only from certain point sources. Total particulate matter is addressed by USEPA regulations in both ambient air and from most point sources. However, welding operations are usually small enough that they are *not* regulated as point sources. Total particulate matter may be regulated as fugitive emission sources, but only as part of the total emissions from a facility.

OSHA permissible exposure limits (PEL) regulate industrial exposures to NO_x components, nitric oxide (NO), and nitrogen dioxide (NO_2), at PEL/TWAs of 30,000 µg/m^3 and a ceiling limit of 9,000 µg/m^3, respectively. The PEL/TWAs for CO and O_3 are 50,000 µg/m^3, and 100 µg/m^3 respectively. OSHA also has TWAs for most metals in addition to Cr^{+6}. These are listed in Table 4-1 (end of Section 4.0).

1.4 STAKEHOLDER/END-USER ISSUES

The stakeholders and end-users of PPI technology are: facilities that perform welding; companies that have developed and manufacture PPI welding equipment; regulatory

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* The ceiling for "chromic acid and chromates", which are the only forms of hexavalent chromium listed in tables Z-1 and Z-2, were 1mg CrO_3/10m^3, which is equivalent to 100 µg CrO_3/m^3. CrO_3 is 52% by weight Cr; therefore, the effective Cr ceiling limit was 52 µg Cr/m^3.

agencies such as USEPA and OSHA, who are obligated to protect workers and the public from potential emissions; workers who are exposed to welding fumes; and the general public who breathe the air near welding operations.

For welding facilities, PPI technology must produce welds whose quality and integrity are comparable to conventional pulsed power technology. Ideally, the emissions from PPI should be no greater than that from conventional technology, or there may be additional costs associated with worker protection, and fugitive dust emission controls. In particular, metal emission factors should be determined, especially for metals that are believed to be relatively toxic, such as Cr^{+6}, copper, manganese and nickel.

Companies that manufacture wire-welding equipment (e.g., Hobart, Lincoln Electric, ESAB, Miller, etc.) clearly have a financial interest in supplying reliable, economical, and otherwise competitive welding technologies. Such competitive edge is influenced by fume emission production.

The legal community is a recent addition to stakeholders particularly with respect to welding and manganese. Several recent studies indicate that exposure to manganese generated during welding may lead to central nervous system damage that manifests itself with early-onset Parkinson's-like symptoms. [(3)(4)(5)] Results are inconclusive with conflicting reports from both sides of the issue. There is an aggressive effort by some in the legal community to bring cases against welding operations. For example, an October 2009 web search for manganism, legal and welding evokes over 100,000 hits.

USEPA and OSHA professionals advocate for the health of the general public and workers respectively. They must ensure that the emissions produced from any technology do not create excessive health risks. To accomplish this end it is important that they have access to unbiased emissions data.

2.0 DEMONSTRATION TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

Electric arc welding is a technology that has commonly been used for decades to metallurgically bond two similar pieces of metal together. During electrolytic welding two pieces of metal are placed next to each other and an electric current is passed between the metals being joined and a consumable rod or wire electrode of compatible composition. The electric current generates sufficient heat to cause the electrode and a portion of the metals being bonded to melt. Upon cooling, the pieces being bonded form one essentially uniform piece. Initially, metal welding rods were used as the sacrificial electrode. Each rod was coated with a "flux" material (for steel alloys the flux is limestone i.e., calcium carbonate based) to inhibit oxidation of the parts being bonded. "Stick" welding (i.e., using rods), also called Shielded Metal Arc Welding (SMAW), is an intermittent process. That is, if a weld consumes more than one rod, then additional rods are used, until the full length of the weld is completed. SMAW continues to be a popular welding technique especially in difficult to access locations and quick welding tasks. Stick welding processes do not use a shield gas.

In wire welding, a roll of wire is continuously fed to the weld site. The wire may be solid or it may have a flux "core" (i.e., the wire has a hollow cross section, the center of which is filled with a chemical flux). Regardless of whether the wire welding process is Flux Core Arc Welding (FCAW), or Gas Metal Arc Welding (GMAW), the welding is done under an inert shield gas. The inert shield gas provides the primary or additional protection from oxidation. Inert gases used during the welding of steel alloys are primarily argon in combination with smaller percentages of carbon dioxide and/or oxygen. Stick welding is reported to produce more airborne particulate matter than wire welding. The particulate matter is primarily metal oxides, which are minimized by using inert shield gases.

PPI is a wire welding technique that *looks* similar to conventional pulsed power wire welding, in which the electrical current is carefully controlled to melt the metal parts (i.e., the welding wire and portions of the metal parts being joined). This is made possible through the latest achievements in solid-state electronics technology. The electrical current waveform characteristics (e.g., pulse frequency, background and peak current, rise time) are continuously adjusted electronically to provide more precise control of the welding "arc". Older conventional transformer-rectifier power supplies may have slower response times for the ramp-up of welding current from background to peak values. PPI allows responses in the range of milliseconds (See typical waveform graphs in Waveform (Appendix D). This control permits easy alteration of the welding waveform through available software packages, to custom design and optimize the waveform for any application. The precise control of welding parameters prevents overheating and uncontrolled vaporization of the welding wire as it melts and transfers to the molten weld pool during welding. Spatter and fume generation are also decreased in the process. The solid-state construction of PPI units makes them lighter and more compact than conventional transformer-rectifier systems. Manufacturers have cited the ability to meet worker safety and environmental requirements without the use of additional engineering controls to extract fumes.

In this demonstration, all three welding technologies, SMAW, GMAW, and FCAW are compared with the use of Pulsed Power Inverter (PPI) welding during field (non-laboratory) operations.

2.2 TECHNOLOGY DEVELOPMENT

According to recent literature, use of PPI can result in generation of lower fume levels than conventional pulsed power welding operations because of controlled droplet size and use of lower average welding current. A 1993 laboratory study by Harvey Castner (6) compared pulsed current gas metal arc welding (GMAW) to steady current GMAW. This paper describes a study of the effects of pulsed welding current on the amount of welding fume and ozone produced during GMAW using a range of welding parameters. Fume generation rates were measured for steady current and pulsed current GMAW of mild steel using copper-coated ER70S-3 welding wire and 95%Ar-5% CO_2 and 85% Ar-15% CO_2 shielding gases. The amount of fume generated during welding was determined by drawing fume through a fiberglass filter using the standard procedures contained in ANSI/AWS F1.2. Results of these measurements show that pulsed welding current can reduce fume generation rates compared to steady current. There is a range of welding voltage that produces the minimum fume generation rate for each wire feed speed with both pulsed and steady current. The data also show that using pulsed current does not guarantee lower fume generation compared to steady current. Welding parameters must be correctly controlled if pulsed current is to be used to reduce fume levels. Fillet welds were made to demonstrate that the pulsed current welding parameters that reduce fume also produce acceptable welds. No significant difference was found in the chemical composition of fumes from pulsed current compared to steady current. Fumes generated by both types of current are mixtures of iron, manganese and silicon oxides. Measurements of ozone generation rates show that the pulsed current welding parameters that reduce fume also increase ozone generation compared to steady current welding. An in-depth survey report by U.S. Department of Health and Human Services (7), focused on process modification as a method to eliminate or reduce the ventilation during GMAW. Many of the welders in this study used PPI technology, rather than conventional pulsed power welding power sources. Results from the study concluded that total welding fume and elemental exposures were significantly lower (24%) during PPI welding compared to conventional pulsed power arc welding. The California Air Resources Board (CARB) (8) studied both mild and stainless steel welding processes to determine welding emission factors for several processes and confirm results from several particulate studies. CARB found that for pulsed GMAW an increase in fume generation rates correlated with an increased particle size. In addition, pulsed GMAW reduced the grams of particulate matter ($PM_{2.5}$) per kg of electrode used by 30%-40%, when compared to conventional GMAW welding. Although there was a slight decrease, there was a smaller percentage reduction (less than 10%) in grams of Cr^{+6}/kg of electrode. Other studies indicated similar results. (9, 10, 11) Prior to the beginning of this study, several manufacturers advertised significant reduction in the range of 50 to 80% reduction in fumes. Several original advertisements, case studies, technical presentations and abstracts shown in Appendix K.

2.3 FACTORS AFFECTING COST AND PERFORMANCE

The elements that contribute to developing a cost analysis of PPI use versus conventional use of pulsed power welders are:

- The capital cost of the welding equipment.
- The labor hours required to make a specific length of weld (with all other parameters kept the same).
- The electrical costs associated with a specific length of weld.
- The costs of the welding wire associated with a specific length of weld.

In addition, the quality of the weld achieved using both welding techniques is of paramount importance, and can be evaluated by measuring the weld's tensile and yield strengths, ductility, toughness and other metallurgical characteristics.

It is not expected that the quantity or quality of fumes generated by either technology will result in different personnel protective equipment (PPE), or in area ventilation practices. Consequently, the costs of such equipment are not considered to be a factor for this analysis [5].

3.0 PERFORMANCE OBJECTIVES

3.1 PERFORMANCE OBJECTIVES

The determination of environmental/health impacts was the primary goal in collecting environmental performance data. Nevertheless, it is recognized that positive environmental/health impacts are of marginal benefit if weld quality is sacrificed. Therefore, performance data were collected to determine both: (1) the environmental and human health impact of welding fumes, from both conventional pulsed power and PPI activities, as well as (2) to determine the quality of the weld using PPI welding technology. Table 3-1 lists the performance criteria.

Table 3-1: ESTCP Performance Criteria

Performance Criteria	Description	Primary or Secondary
Weld Quality	Produce welds that meet or exceed quality control concerns and operational process specifications	Primary
HAP Emissions	Reduce HAP emissions, particularly Hexavalent Chromium and Total Chromium, Manganese, Nickel, Copper, Molybdenum and other metals found in welding operations.	Primary
Criteria Pollutant Emissions	Reduce NO_x, Ozone, CO (incidentally CO_2)	Primary
Occupational Exposures	Reduce worker exposures, particularly Hexavalent and Total Chromium, Manganese, Copper and Nickel.	Primary
Worker Safety	UV light emissions (Item is secondary because workers already wear PPE. Goal was to determine if increased UV occurs.)	Secondary
Worker Acceptance	Worker comments on ease/difficulty of use, system preference, optimization settings	Secondary
Ease of Use	Skill level of personnel required to use equipment effectively. Identify additional training required.	Secondary
Versatility	Used effectively on various welding applications demonstrated.	Secondary

3.2 PERFORMANCE CONFIRMATION METHODS

Table 3-2 outlines the expected and actual performance criteria generated during testing.

Table 3.2: Performance and Performance Confirmation Methods

Performance Criteria	Expected Performance (pre demo)	Performance Confirmation Method	Actual Post Demo
PRIMARY CRITERIA (Performance Objectives) (Quantitative)			
Hazardous Contaminant			
– Heavy metals – Hexavalent Chromium – Carbon Monoxide	Reduce by 40% Reduce by 30% < PEL	NIOSH method 7300 OSHA method ID-215 OSHA method ID-209	No change No change No change but confounded by other local equipment
– Ultraviolet Non-Ionizing Radiation	Slight increase	NEHC TM IH 6290.91	Slight decrease
– NO_x – Ozone	No increase Slight increase	Continuous monitoring NEHC TM IH 6290.91	No increase Decrease
Material Quality			
– Weld Reliability	Meets facility destructive & non-destructive test requirements	Specifications to be provided by individual facility	Similar Results Accept & unacept. evals found in both baseline & test plates
SECONDARY PERFORMANCE CRITERIA (Qualitative)			
Productivity			
– Reduce spatter – Reduce rework	Yes Increase duty cycle by 10%	Experience from demonstration	Achieved Mixed Results
Safety			
– Protective Equipment	Avoid respirator usage anticipated under new OSHA regulation	Experience from demonstration	Depends on alloy & space
– Heat Stress	Slight increase	Wet Globe Bulb Temperature (WGBT)	Deleted from test
– Ventilation	Avoid installation as anticipated under new OSHA regs	Experience from demonstration	Depends on alloy & test
Scale-up Constraints			
– Optimization	Perform as advertised when equipment is delivered	Experience from demonstration	Optimal Envi Settings did not coincide w/good weld quality
Ease of Use			
– Training	3 day hands on training	Experience from demonstration	Likely to be sufficient
SECONDARY PERFORMANCE CRITERIA (Quantitative)			
Cost			
– Energy Usage	Decrease by 20%	Cost calculations	Decrease less than 20% Varied w/ location
– Equipment payback	5 years		Undetermined Varied w/ location

3.2.1 Environmental/Industrial Hygiene Criteria. The primary goal of this field demonstration is to compare the emissions/exposures from PPI welding to conventional pulsed power welding techniques. For this comparison, there are no criteria, other than to determine which welding technique is better (i.e., lower concentration emissions) than the other for each measured parameter. The secondary goal is to compare welding emissions/exposure to appropriate EPA and OSHA criteria, where available. There are no specific EPA emission criteria for welding operations (although Cu, Ni, Mn, Cr^{+6}, etc. are EPA HAPs). OSHA criteria for Cr^{+6} and gaseous emissions for industrial processes were discussed in Section 2.4. In addition, Table 4-3 (at the end of Section 4.0) shows current NIOSH and OSHA time weighted average [TWA] occupational hygiene limits for all the metals that were analyzed. It must be emphasized, that in this demonstration the welding location was ventilated by the exhaust hood used for air sampling. Therefore, the IH exposure data collected will not reflect welder exposure in unventilated or cramped locations. Most work was performed in open bays. The exception is that the welder at SWRMC worked in a semi-enclosed tent-like area covered on three sides and overhead. In addition, the industrial hygiene samples were engineering samples and not samples taken directly in the welder's breathing zone. Engineering sample terminology is used by NIOSH to indicate area sampling procedures before and after the application of a particular technology. The sampling cassette containing the filter is is placed near (within 12 inches) the welding operation.

3.2.2 Weld Quality Criteria. The conformance to criteria for weld quality was determined by tests designed to measure the tensile strength, yield strength, ductility and the Charpy V-Notch (CVN) strength of the weld material. These parameters were compared to acceptable values or ranges that have been established for the metal alloys and welding techniques in question. These tests were performed on at least two samples from each of the test facilities.

3.2.3 Cost Criteria. The cost of the capital equipment, labor to weld a specified length of weld, electrical usage per specified length of weld, and the consumption of welding wire per specified length of weld are determined in Section 5. The short duration of the test did not permit the determination of a payback period.

4.0 SITE/PLATFORM DESCRIPTION

An initial laboratory evaluation by the Naval Surface Warfare Center Carderock Division (NSWCCD) on several welding machines, ultimately shipped to field sites, attempted to optimize the fume generation rate by electronically adjusting the pulsed power settings. Computer optimization was a marketing point for one manufacturer. The report, *Evaluation of Inverter welding Power Supplies as a Means of Reducing Welding Fumes* prepared by K Tran and G Franke, is included as Appendix J (12).

At the field sites, the objectives for sampling the gases, particulates, and ultraviolet (UV) radiation from welding operations were to determine the environmental and human health impacts of welding operations in general and, in particular, to determine if there is a statistically significant difference between emissions from pulsed power inverter welding and conventional pulsed power welding. Likewise, the mechanical characteristics of the welded test plates from PPI welding were compared with standard specifications that must be met by conventionally welded plates, such as tensile and yield strengths.

4.1 SELECTING TEST SITES/FACILITIES

The laboratory tests noted in Section 3.1 were conducted at NSWCCD, West Bethesda, MD. NSWCCD welding laboratory personnel have extensive experience and equipment to evaluate welding operations, especially for shipbuilding operations. The selected field tests sites are those that routinely perform extensive welding operations using steel and chromium-containing alloys for repair of ships, landing vehicles, and other military transportation equipment. A cross-section of DOD operations was desirable. Ultimately Navy (Puget Sound Naval Shipyard [PSNSY], Bremerton, WA and Southwest Regional Maintenance Center [SWRMC], San Diego, CA), Army (Anniston Army Depot [ANAD], Anniston, AL), and Marine Corps (Marine Corps Logistics Base [MCLB], Albany, GA) operations were chosen.

ANAD has a reputation as “The Tank Rebuild Center of the World”. As such ANAD performs depot-level maintenance for combat tanks, tracked combat vehicles, small arms weapons, mortars, recoilless rifles, and fire control systems.

The maintenance centers at MCLB provide maintenance support for Marine ground weapon systems, such as: automotive, engineer, and combat vehicles; and communications, electronics, radar and missile systems.

PSNSY is the largest and most diverse shipyard on the west coast, and is the northwest’s largest naval shore facility. Approximately 30% of PSNSY’ workload involves inactivation of nuclear vessels, reactor compartment disposal, and recycling of ships. They have the capability to overhaul and repair all types and sizes of US Navy ships. In 2000, the Chief of Naval Operations recognized PSNSY for its environmental achievements.

SWRMC is the Southwest's single point of ship maintenance with a mission to provide ship repair, industrial, engineering and technical support for the Navy; to procure and administer contracts for accomplishment of required maintenance and modernization performed on naval ships at private yards; and to train sailors in maintenance and repair of shipboard systems and components.

4.2 PRESENT OPERATIONS

As noted earlier, PPI technology is promoted as producing less metal-bearing particulates because less slag and spatter take place. This is particularly important with respect to chromium-containing alloys, such as HY-80 and "chrome-moly" alloys, commonly used in DOD applications, because hexavalent chromium emissions are stringently regulated under OSHA. (In January 2006, OSHA promulgated [71 FR 10100 – 28 Feb 2006] about a 10-fold tightening of its standards to a permissible exposure limit [PEL] of 5.0 micrograms/cubic meter [$\mu g/m^3$] of Cr^{+6} on a TWA basis. (See Section 1.3)[(2)] Also, less slag and spatter should result in reduced welding time. In addition, PPI reportedly will generate less ozone, carbon monoxide, and oxides of nitrogen than conventional pulsed power welding. These gases are formed when electrical arcs are exposed to air. The OSHA recommended TWA exposure limit for ozone is 100 parts per billion by volume [ppbv], for CO it is 50,000 ppbv, for nitrogen oxide (NO) it is 25,000 ppbv, and for nitrogen dioxide (NO_2) it is 5,000 ppbv.

There should not be any functional limitations of PPI application, because it is almost identical in use and application to conventionally powered wire welding. In addition, PPI training for welders that are already experienced with wire welding should be minimal.

5.0 TEST DESIGN

Currently, DOD artisans conduct welding operations at most of its facilities. However, extensive welding operations are conducted at heavy equipment maintenance and rebuilding facilities, such as those discussed in Section 4.1, at which this project was conducted. At those facilities, virtually every form of modern rod and wire welding is used, to include SMAW, GMAW, FCAW, with conventional pulsed power. Welding operations are conducted using various substrate metals, such as conventional mild steels, high strength mild steels, alloy steels containing relatively low levels of nickel and chrome (e.g., HY-80, 4130), some stainless steel alloys, and aluminum alloys. Aluminum and stainless steel were not evaluated during this demonstration. This demonstration was limited to mild steel, hardened steel and steel alloys since they constitute the bulk of the work performed at the selected facilities.

5.1 PRE-DEMONSTRATION TESTING AND ANALYSIS

No preliminary bench-, pilot-, or full-scale Pulsed Power Inverter technology testing was conducted prior to this project. The PPI technology is a commercial off the shelf (COTS) item. This project was designed to replicate actual full-scale production welding techniques, using test plates representative of actual materials used on DOD vessels and vehicles at each facility.

5.2 TESTING AND EVALUATION PLAN

The following subsections describe the test plan design and setup, to include choosing the test locations, selecting the alloys to be welded, and other relevant planning information. The testing was conducted according to the *ESTCP Demonstration Plan, Pulsed Power Inverters in Welding Applications*[1], and modified in the field as necessary.

5.2.1 Demonstration Set-up and Start-up. Field-testing was conducted at:

- MCLB, Albany, GA during the weeks of 15 September 03, and 17 November 03;
- ANAD, Anniston, AL during the weeks of 20 October 03 and 27 October 03;
- PSNSY, Bremerton, WA during the weeks of 9 August 04 and 16 August 04; and
- SWRMC (formerly SIMA), San Diego, CA during the weeks of 27 September 04 and 4 October 04.

The typical physical setup of the test areas at each of the four test facilities are shown in Figures 5-1 through 5-4. During testing at each facility the welder sat or stood at a specified location, and welding was conducted on steel plates that were located approximately 12 inches from a fume inlet hood. The fume inlet hood was connected through transition pieces to a 12-inch diameter polyvinyl chloride (PVC) duct. Welding fumes were drawn through the duct by a suction fan, which developed about 650 dry standard cubic feet per minute (dscfm) of volumetric air flow. Modified USEPA Method 5 particulate samples were isokinetically withdrawn from the duct through a 9-stage cascade impactor (CI). The CI separated particulates into 9 size-range fractions. Welding fumes were also withdrawn from the duct continuously and passed through CO, O_3, and NO_x real-time continuous emissions monitors (CEMs).

Figure 5-1: Stack Sampling Train

Figure 5-2 Instruments

Figure 5-3: Cascade Impactor

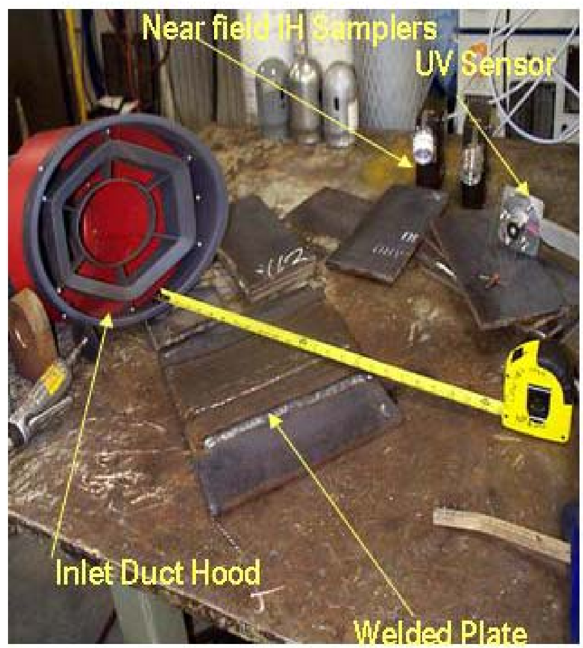

Figure 5-4: Duct Inlet at Weld Site

To measure occupational exposure to particulate matter, two industrial hygiene area-sampling pumps were set up about 1 to 2 feet from the weld site, and typically 90 degrees from the collection hood, using the welding operation as the center. Two additional pumps were posted about 10 feet from the weld site. One pump at each location sampled for Cr^{+6} using an OSHA Method 215 PVC filter, and the second pump at each location sampled for all other metals using an NIOSH Method 7300 mixed cellulose ester (MCE) filter. In addition, UV exposure was measured using a sensor placed approximately 2 feet from the weld site.

Welders joined 12-inch test plates for later non-destructive testing by the local welding engineer or at NSWCCD. Selected test plates were subjected to full mechanical evaluation at NSWCCD. Tests focus on the weld and heat affected zone of the weldment. In addition to test plates, the welder conducted a “bead on plate” operation to generate fumes for the remainder of the time. A bead is laid down adjacent to the previous bead until the whole plate is covered with filler metal. Bead on plate welding is typically done to practice a new technique, evaluate a new piece of equipment, etc. This demonstration used the bead on plate process to generate fume to meet the limit of detection (LOD) for the collection media. These plates are typically not fully cooled between passes and tend to receive a higher heat input per pass because weld quality was not a concern during Bead on plate welding. Discussions with several welding experts, in the weld engineering and the occupational health, safety and environmental communities, concurred that the extra heat input would not alter the quality of the fume.

5.2.2 Period of Operation. Testing was conducted at the locations and time periods noted in Section 5.2.1.

5.2.3 Materials Used. Welding was conducted with various combinations of welding processes, rods and wires, and on various steel alloy test plates. All were consumables, base materials and processes typically used at the activity. At ANAD and MCLB, testing was conducted only on mild (also called ordinary and low carbon) steel alloys, such as type 1018, type 1020, or armored steel. Each of these contains typically less than 0.1% chromium, and less than 0.01% nickel. Armored steel is specially heat treated in a proprietary process. At PSNSY welding was conducted on mild steel alloys and on HY-80. PSNSY weld engineers reported that HY-80 contains from 1-2% chromium, and 2-3.5% nickel. At SWRMC welding was conducted on mild steel and 4130 steel (chromium/molybdenum (Cr-Mo) alloy). SWRMC weld engineers reported Cr-Mo alloy used contained 0.8% chromium, and 0.2% nickel. All metal alloy percentages are based on information provided by the activity.

Metal percentages in the consumables were provided by the local activity and from the Material Safety Data Sheet (MSDS) associated with the rod or wire. Consumables (welding rods and wire) used throughout were typically less than 0.5% chromium, and less than 0.2% nickel. The exceptions were for:

- at SWRMC: (a) on 1 October, 2nd run & 4-5 October, ER80SB-2 wire, which contained about 1.2% chromium; (b) 11018 rod, which contained

1.25–2.5% nickel; and (c) on 6-7 October, 9018-B3L rod, which contained 2.0-2.5% chromium; and

- at PSNSY: (a) on 10 August, 81T1Ni2M, flux core wire, which contained 1.75-2.75% nickel; (b) on 12 August, 11018 rod; and (c) on 16-18 August, 100S-1 wire, which contained 1.4-2.1% nickel.

The demonstration plans calls for testing aluminum processes. Aluminum welding processes were eliminated due to the longer than expected time to reach a limit of detection for the steel welding processes.

5.2.4 Residuals Handling. The scrap materials generated during testing were scrap metals and test plates, none of which are considered hazardous materials or hazardous wastes, and all were eventually recycled as scrap metal.

5.2.5 Operating Parameters for the Technology. The more critical independent variables for this testing protocol are given below. These parameters were developed based on telephone interviews, standard operation procedures for the participating facilities and welding standard reviews. In Section 6.1.1 there is a more detailed discussion of these and other independent and dependent variables.

- welding speed, which can be expressed as length of weld per unit arc time (Arc time is the time that welding wire/rod is actually being consumed, as opposed to conducting associated operations such as cooling, grinding and slag removal.),
- rod or wire consumption speed, as measured in length per unit time, also related to welding speed and frequently tracks amperage,
- type and thickness of rod/wire used,
- type of alloy being welded,
- inert gas composition and flow rate (for GMAW),
- amperage/voltage settings (also related to welding speed),
- for PPI, the software “program” chosen for welding,
- ventilation-related issues, such as air flow through the shop, mechanical or ambient welding ventilation,
- orientation of the part being welded (horizontal or vertical, corner or flat weld),
- type of joint being welded (cross-section of the two edges being joined).

For purposes of this project, arc time was manually tracked using stop watches. Rod/wire consumption was also tracked. Alloys welded and the type and thickness of the welding rod/wire were also documented. Voltage [V] and amperage [A] from the power sources were not tracked on a data logger as originally planned. V and A were hand collected from the machine readouts to evaluate power usage since the machine’s power input cable could not be spliced for connection to a data logger without jeopardizing the warranty. Nor could the building power source be isolated. Environmental air samples were collected via a 9-stage in-stack cascade impactor inserted in a nominal 12-inch polyvinylchloride (PVC) pipe/duct exhausted with a Lincoln Mobiflex 400-MS low volume vacuum system. Exhaust velocities were typically 100 feet per minute (fpm) at approximately 12 inches from the test weld. However, the distance of the inlet ventilation hood varied somewhat from one weld sample to the other and depended on the plate configuration and test setup. This caused the actual test velocity to range from 46 to 100 fpm. Like ventilation, most of the independent parameters could not be well-controlled. Hence, measured emissions were compared both to arc time and to the amount of welding rod/wire used. No attempt was made to factor most of the other variables.

5.2.6 Experimental Design. As discussed in this section and in Section 6.0, a variety of different parameters were measured. The sampling equipment used is identified as follows:

A modified EPA Method 5 stack sampling train was used to collect particulate matter using a 9-stage Andersen Mark III cascade impactor (CI). Isokinetic samples were drawn at a position of 5 feet 9 inches downstream from the inlet to the aforementioned 12-inch PVC duct (and 1 foot 10 inches upstream from the discharge end of the 12-inch duct). Because the air being sampled was essentially at ambient temperature, it was not necessary to heat the CI. The CI was positioned immediately after the 5/16-inch diameter sampling probe tip. The first 8 stages of the CI each collected a different particle size fraction. The last stage (9th stage) was a final filter, and collected all remaining particles. Figures 5-5 and 5-6 show some of the CI stages broken down after a sampling run. (Note the dark color of the final filter stage in Figure 5-6. This was typical of all runs. The orange color was essentially from iron oxides.) At the sampling velocity used, the fractions were approximately:

- The 1st stage collected the largest particle size fraction – those particles were about 13-20 micron diameter. A pre-separator (see Fig. 5-3) was used upstream of the CI. It removed particles larger than about 20 microns.
- The 2nd stage collected particles about 8.8-13 microns.
- The 3rd stage collected particles about 6.0-8.8 microns.
- The 4th stage collected particles about 4.1-6.0 microns.
- The 5th stage collected particles about 2.6-4.1 microns.
- The 6th stage collected particles about 1.3-2.6 microns.
- The 7th stage collected particles about 0.8-1.3 microns.
- The 8th stage collected particles about 0.55-0.8 microns.
- The 9th stage was a final filter, collecting all remaining particles smaller than about 0.55-micron diameter.

It should further be noted that the particle size cut point for each stage is based on particles whose density is 1 gram/cm^3. Metal oxide particles would be expected to be denser than 1 gram/cm^3. Therefore, the particle size ranges are probably overestimated (i.e., the particle size range collected on each stage is probably smaller than listed above).

Each of the 9 stages collected particles on media that was fabricated of 63-millimeter (mm) diameter glass fiber media material. After gases passed through the CI, they entered four glass impingers, in series, that were chilled in an ice bath. The sole purpose of the impingers was to collect moisture in the air stream to facilitate the determination of the degree of isokinicity.

> Note: At 100% isokinicity, the velocity of the air flowing in the 12-inch poly vinyl chloride [PVC] sampling duct is identical to the velocity of the air being drawn into the sampling probe tip. When 100% isokinicity is not achieved the measured concentration of particulates in the air stream will be skewed either high or low. EPA's Method 5 allows isokinicity values of 100± 10%.

The first two impingers were each initially filled with 100 milliliters (ml) of tap water. The 3rd impinger was empty, and the 4th was filled with approximately 200 grams of silica gel to absorb all final traces of moisture.

PVC and Teflon® tubing were used to deliver the welding fume stream from the 12-inch PVC duct into each of three CEMs. These samples were withdrawn from a location about 4-½ feet upstream from the Method 5 sampling probe. CO was monitored using an Advanced Pollution Instrumentation Model 300M Analyzer. $NO_,$ NO_2, and NO_x were monitored using either an Advanced Pollution Instrumentation, Inc. Model 200A chemiluminescent analyzer, or a Thermo Environmental Instruments Model 42 chemiluminescent analyzer. O_3 was monitored using a Thermo Environmental Instruments Model 49 UV Photometric Ozone Analyzer. Each of the CEMs was calibrated using a Thermo Environmental Instruments Model 146 Multigas Calibration System. Compressed calibration gases (NO and CO) were delivered at certified concentrations in nitrogen. Calibration of the O_3 monitor requires only "zero" concentration compressed air.

Figure 5-5. Separated Cascade Impactor Stage "Filters" After Sampling

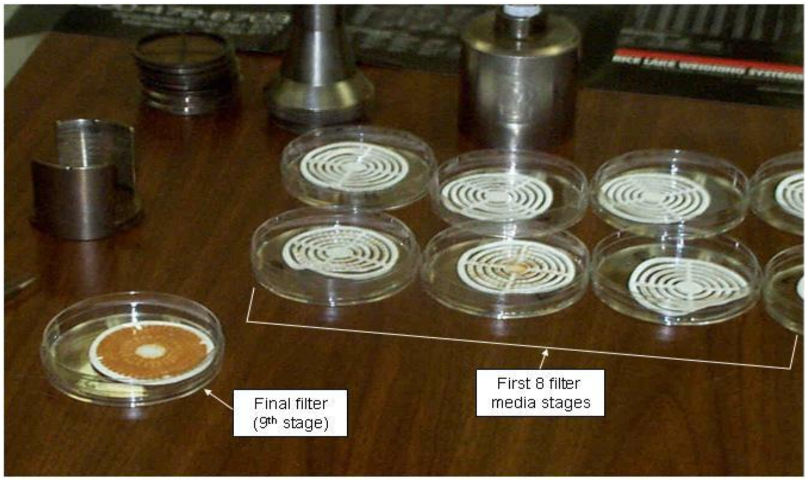

Figure 5-6. Separated Cascade Impactor Stage "Filters" After Sampling

An International Light, Inc. Model IL1430 Radiometer/Photometer was used for monitoring ultraviolet (UV) light in the range of 200 – 400 nanometer (nm) wavelength (which encompasses the UV-A, UV-B, and most of the UV-C ranges). However, UV light emission was only monitored at PSNSY and SWRMC. The instrument sensor head was positioned about 2 feet from the welding site, located in approximate line-of-sight from welding activities. At MCLB and ANAD the test equipment was sensitive to visible light rather than UV emissions, and did not produce usable results; hence it was replaced with the International Light sensor.

A data logger was used to store readings from the three CEMs as well as the UV monitor every 15 seconds at SWRMC (and every 30 seconds at PSNSY). Data were downloaded at the end of every sampling day.

Four SKC Model PCXR4 Universal Sampler pumps were used to collect IH samples approximately 8 hours each sampling day, and were calibrated each day with a BIOS DC-Lite Electronic Flowmeter. OSHA Method 215 samples for hexavalent chromium were taken using a flow rate of about 2 liters per minutes. NIOSH Method 7300 samples for all other metals were taken at about 4 liters per minute.

Welding quality was evaluated using the test methods specific to the facility's operations. Non-destructive tests were conducted by the local activity or NSWCCD. Non destructive evaluation (NDE) tests include a visual examination, liquid penetrant, and radiography. Other available NDE examinations are gamma radiography ultrasonic, magnetic particle, eddy current, acoustic emission and leak test. NDE tests are performed during the day to day operations at a welding facility. Depending on the local performance requirements, facilities conduct different NDE tests and typically report the sample as passed or failed.

Destructive testing followed the American Welding Society Standard: B4.0 Standard Methods of Mechanical Testing of Welds and other specifications particular to the application, process or metal. Destructive testing is usually preformed to qualify a welder, qualify a procedure specification or for periodic qualification records. NSWCCD welding laboratory technicians and engineers took specimens from the weld itself and the test plate's heat affected zone. They machined samples for the following weld destructive weld parameter test: chemistry, tensile yield strength, ultimate tensile strength, percent elongation, and CVN energy.

5.2.7 Demobilization. This demonstration project was not intrusive, i.e., there were essentially no modifications made to existing facility equipment. Therefore, when sampling was completed at each facility, sampling equipment was put back in its original containers, and shipped back to the appropriate locations. The host facility received the PPI machine as part of their compensation for participating in the study. No repairs or modifications had to be made to the host facility.

5.3 SELECTION OF ANALYTICAL/TESTING METHODS

Metals detection analysis for 20 metals plus hexavalent chromium (Cr^{+6}) were performed on each of the nine-stage CI "filters" as well as the filter media for the IH samplers. All metals analyses (except Cr^{+6}) were conducted by using modified NIOSH Method 7300, Inductively Coupled Argon Plasma, Atomic Emission Spectroscopy [ICP-AES]. Hexavalent chromium was analyzed using modified OSHA Method 215, which uses an ion chromatograph [IC] equipped with a UV-vis detector technology. Each of the nine-stage CI particulate media was cut in half to accommodate the two different test methods (i.e., half for Cr^{+6}, and half for the other 20 metals).

Each of the nine-stage CI filters was weighed on a balance prior to and after each sampling run to determine gravimetrically the weight gain on each stage. All filters were desiccated prior to weighing. Balances were accurate to 0.1 mg (0.01 mg at MCLB).

Assembling and disassembling CI stages resulted in mechanical loss of a small quantity of filter media material from each stage. To compensate for such losses, numerous blank CI filters were analyzed for metals (typically two blanks each week for the perforated filters used for stages 1-8, and one blank each week for the non-perforated 9th stage filter). In addition, an entire 40-minute "run" was made with a CI whose inlet air was filtered through a High Efficiency Particulate Air (HEPA) filter to assist in determining weight loss due to mechanical attrition as well as to quantify blank (i.e., clean filter) metal content.

5.4 SELECTION OF ANALYTICAL/TESTING LABORATORY

The Consolidated Industrial Hygiene Laboratory professionals, at Naval Environmental and Preventative Medicine Unit #5, Naval Station, San Diego, CA performed all metal analyses for environmental and industrial hygiene samples. The laboratory is certified under the American Industrial Hygiene Associations, Proficiency Analysis Testing Program. Each facility personnel performed the initial non-destructive testing on the test plates. Selected non-destructive testing and all metallurgical quality analysis were performed by the Naval Surface Warfare Center technicians, Carderock Division, West Bethesda, MD.

6.0 PERFORMANCE ASSESSMENT

6.1 DATA ANALYSIS, INTERPRETATION AND EVALUATION

The initial pulsed power inverter machine evaluation at NSWCCD showed that the system could be optimized for fume emission control. However laboratory metallurgical testing for weld quality indicated that manufacturer's recommended operating point was a representative balance between material quality and environmental emissions. When the equipment was brought into the field the welders always used the manufacturer's recommended settings rather than the NSWCCD-optimized settings because they believed they were not able to weld as well with the optimized settings. If more time had been available for welder training on the PPI equipment, emissions might have been further minimized.

The following subsections discuss the environmental data (i.e., ventilation duct samples), industrial hygiene data (i.e., area samples from IH pumps), and weld quality data; and interpret and evaluate their meaning.

6.1.1 Environmental/Industrial Hygiene Data. Environmental data were taken from samples withdrawn from the duct used to ventilate the welding operations as follows: (1) Continuous Emissions Monitoring (CEM) data for CO, NO_x, and O_3, and (2) particulate samples taken using a 9-stage cascade impactor (CI). Each impactor stage was weighed to determine gravimetrically the quantity of total particles collected on each stage (i.e., desiccated weight after sampling minus desiccated weight prior to sampling). In addition, each of the CI stages was analyzed for 21 individual metals (including Cr^{+6}).

Industrial hygiene information (i.e., occupational exposure) was estimated from particulate area samplers positioned both near-field (1-2 feet) and remote or far-field (about 10 feet) from the welding operation. Filters from one of the two near-field samplers and one of the two far-field samplers were analyzed for Cr^{+6}. Filters from the second near-field sampler and the second far-field sampler were analyzed for the same metals (not including Cr^{+6}) as the above-mentioned CI stages. Each IH sampler accumulated approximately a full day's welding emissions. In addition, UV exposure was monitored, real-time, by an UV sensor placed about 1- 2 feet away from the weld site (only during sampling at PSNSY and SWRMC).

Before discussing the environmental and occupational health sampling data, it is important to understand that the quality of the data is limited by a number of factors that were difficult to control during welding/sampling operations. Some of these factors varied within each facility as well as between facilities, and others only varied between facilities (e.g., the distance between the welded plate and the inlet ventilation duct at ANAD was different than it was at PSNSY). These factors are as follows:

Factors Varying Within *and* Between Each Facility

- Variations in welding technique by each welder, both *intra*-welder (e.g., one welder was distracted by family events throughout the day), and *inter*-welder (e.g., one welder welds more rapidly than another welder, left/right handedness, etc.).
- Cross-currents and breezes in the welding area (although attempts were made to minimize cross-currents as much as possible).
- Orientation of the welded part (e.g., vertical/flat weld position, weld at a corner).
- The type of welding media (e.g., solid wire, flux-core wire, welding rod [“stick”]).
- Type of inert gas shield (e.g., 95% argon-5% carbon dioxide, 75% argon-25% carbon dioxide, 98% argon-2% oxygen).
- Wire/rod diameter and wire speed.
- Cooling time allowed between passes.
- Amperage/voltage variations.
- Multiple combinations of plate substrate (e.g., mild steel, HY-80) and wire/rod type (e.g., flux core versus solid, steel composition).
- Weight loss CI “filter” media due to mechanical filter management requirements. The filter weight loss was compensated as much as possible using blank sample weight loss for comparison. Errors caused by the presence of aluminum, barium, and zinc in CI “filters”.
- Blocking of the ultraviolet (UV) sensor caused by orientation of welding materials and the welder’s body.
- The effect of emissions from local grinding and other metal fume-generating operations.

Factors Varying Only Between Facilities

- The type of joint being welded (e.g., “K”, “V”, and “J”-shaped joints).
- The distance from the point of welding to the ventilation duct inlet (i.e., the greater the distance the poorer the relative fume capture), in addition to the duct orientation (e.g., above, or to the side of the welder).
- The type of “steel” alloy being used (e.g., “mild” steel, HY-80, “chrome-moly”).
- Thickness of steel plates.
- Combustion processes within the test facility (e.g., fork lifts, trucks, heating systems).
- Test facility ceiling height variations.

6.1.1.1 Environmental Data. Environmental data consist of CEM data on CO, NO_x, and O_3 emissions and CI gravimetric and metal analysis data. (CO, NO_x, and O_3 emissions also have worker impact, and are regulated by OSHA. However, they will be discussed in this section rather than in the IH Data Section – 4.3.1.2.) The CO data will not be presented here for two reasons. (1) The OSHA TWA for CO is 50,000 ppbv. At no time were CO concentrations observed to be above about 2,000 ppbv, therefore, nowhere near concentrations of occupational exposure concern. Also, there are no USEPA regulatory limits on CO from welding operations. (2) There were significant uncontrollable sources of CO in the welding area (e.g., fossil fuel forklifts, trucks, torch welding, gas heating systems).

Ozone (O_3) Data:

With respect to the CEM data for O_3, it appears that O_3 concentrations are higher with conventional pulsed power welding than with PPI. The figures for SWRMC, 7 October and SWRMC, 4 October in the CEM Appendix (Appendix E) are fairly typical of the CEM printout data for conventional pulsed power and PPI welding respectively. The purple lines on each figure are O_3. The average O_3 concentration during conventional pulsed power welding is in the 60 – 110 ppb range. With PPI, the range is about 30 – 80 ppb. (Background concentrations were about 20 – 40 ppb.) Caution is urged in attaching too much significance to these finding because the conventional pulsed power welding for the 7 October figure was “stick” welding, *not* wire welding. PPI is used only for wire welding. Where conventional pulsed power wire welding was used, the difference between non-pulsed and PPI O_3 concentrations are not as obvious. Further, the O_3 concentrations at the ANAD and MCLB sites are in the hundreds of ppb range. There is no obvious reason for the difference between sites.

Oxides of Nitrogen (NO_x) Data:

With respect to NO_x concentrations (the blue lines on the graphs in Appendix E, the CEM data are not nearly as definitive as with O_3. At times the NO_x values seem to track welding operations, and at other times they seem independent of welding operations. Part of the problem may be relatively high background values at some sites during certain times (e.g., caused by vehicular traffic). The NO_x concentrations are below 100 ppb almost all the time, regardless of the type of welding being performed. There are excursions as high as 200 ppb or more, but they are rare, and may be associated with other sources of NO_x, or malfunctions of the monitoring equipment. See Figure E-2. Background NO_x concentrations are always less than 20 ppb. Regardless, NO_x concentrations are well below the OSHA TWAs for NO and NO_2 of 30,000ppb and 9,000ppb respectively.

Particulate/Metal Data:

With respect to the size distribution of particulate matter that was collected by the cascade impactor (CI), over 50% by weight was typically collected on the last two stages of the CI during each run (out of a total of 9 stages). This is true for the gravimetric data (i.e., weighing each stage), as shown in the "pie" charts in the Gravimetric Appendix (Appendix F, Figures F-5 and F-6) as well as for metal analysis data, as shown in the metal partitioning graphs in the Metal Partitioning Appendix (Appendix G**).** The last two stages collected particles that are essentially less than 0.8-micron diameter. The last stage being less than 0.55 microns, and the next to last stage is 0.55 – 0.8 microns. This result was expected, because welding fume particles are formed primarily by the condensation and oxidation of vaporized metal particles. Such particle formation is usually sub-micron in size. There is no obvious difference or trend between particle size distribution whether using PPI or not. The smaller particles are of highest concern because they can deposit in the non-ciliated gas–exchange region of the lungs, i.e. alveolar regions of the lungs.

NOTE: At PSNSY, the metal analyses shown in Appendix H, during the second week of sampling (16-19 August 2004), are believed to be flawed, because there are less total metal quantities in the submicron sizes than they are in the larger diameters. (See pages Appendix H(PSNSY) 1-8.) The *gravimetric* data for that week are typical of all other sampling times and locations.

With respect to the relative amounts of each metal species, from 39 to 71% of the metal present, by weight, is iron, by far the most abundant of the metals. This is to be expected when welding steel alloys. Typically, manganese and magnesium were the next most prevalent metals with ranges of 7 to 32% and 5 to 44% respectively. Manganese and magnesium are commonly associated with steel alloys. In addition, arsenic, nickel, strontium, and copper (there is a copper coating on most of the welding wire) appear routinely in the 1 to 5% range. Total chromium appeared in the 1% range only during welding operations on chromium-molybdenum (Cr-Mo) steel at SWRMC; otherwise it was typically less than 0.1%. Metal distributions are shown in the "pie" charts in Appendix G.

It is of interest to note that where chromium emissions were present in measurable quantities (at SWRMC) *during wire (GMAW) welding*, an average of about 8.2% (low of 1.8% and high of 22.9%) of the total chromium emissions were hexavalent. During *"stick" (SMAW)* welding, hexavalent chromium averaged 74.6% of total chromium (low of 39.7% and high of 94.9%). This phenomenon is supported by literature references that suggest that for *stick* welding, the range of hexavalent to total chromium is 47 to 62%, while it is 4% for *wire* welding [13,14,15]. (See data tables in Cascade Impactor Metals Analysis, Appendix H.)

All metal analysis data *exclude* aluminum, barium, and zinc. Aluminum was contained in significant quantity on all 9 stages of the CI substrate media. The other two metals were contained in significant quantities only on the CI final filter stage media (i.e., the 9th stage). Where these metals were contained in the substrates they were at levels that were typically 1,000 times higher than the amount contained in the collected fume. Therefore, subtracting the blank substrate quantities from the actual samples (i.e., the substrate containing the collected fume) still led to artificially high quantities of these three metals in some of the samples. It is believed that these metals were not present in significant quantities in any of the welded metals, or welding materials (i.e., rods, wire, fluxes). Therefore, they were eliminated from consideration. (However, there is some evidence in the literature that aluminum and barium are present in flux core wire welding [FCAW] (16).

There is no obvious trend with respect to which metals predominate when using PPI compared to using conventional pulsed power welding techniques. At SWRMC there was more magnesium than iron during conventional pulsed power welding than during PPI welding (44% magnesium and 39% iron). This is different than for all other locations tested. The difference, however, may reflect the fact that conventional pulsed power welding at SWRMC was done with rod (i.e., "stick" welding - SMAW) rather than with wire. Rods have a flux coating that is predominantly calcium-based salts, such as limestone (essentially calcium carbonate). Limestone compounds are frequently associated with magnesium compounds. All other facilities essentially used wire for their conventional pulsed power welding operations. Similarly, much more magnesium than iron was present at PSNSY when using PPI, but this may be an artifact of the metal analysis error for samples taken during the second week at PSNSY, as noted earlier in this subsection.

Also measured were the quantities of total metals emitted with respect to the actual time that welding was taking place (i.e., when an arc was being struck), as well as with respect to the quantity of welding wire or rod being consumed. If one of the two technologies being compared (i.e., PPI and conventional pulsed power welding) were more environmentally effective, it would be expected to emit less metal fumes for a given length of welding time, or for a given amount of welding rod/wire used. With a few exceptions, emissions of total metals were consistently less than about 150 milligrams per minute (mg/min) of arc time, and less than 10 milligrams per gram (mg/gm) of wire/rod used. This can be seen in Table 6-1 (at the end of Section 6.0) and in the bar charts in Appendix F. There is no obvious difference in these emissions between PPI and conventional pulsed power welding. Consequently and especially given the caveats listed in Section 6.1.1.1, it cannot be concluded that one technology is better than the other with respect to total metal emissions. A possible exception occurred at SWRMC, where PPI emissions as a function of wire/rod used were lower than for conventional pulsed power welding. *But it must again be noted* that conventional pulsed power welding at SWRMC was "stick" welding, not wire welding (GMAW). GMAW is a well-documented improvement over stick welding (9,10,11,17,18). At all other facilities, conventional pulsed power welding was wire welding.

Gravimetric results for total particulate loading for a given amount of arc time or a given usage of rod/wire show the same trends as for the metal analysis data discussed in the last paragraph. However, the gravimetric data (determined by weighing the media on each stage of the cascade impactor) show almost three times the weight of particulate in comparison to the results of total metal analysis (2^{nd} and 3^{rd} columns of Table 6-1). This would be expected, because total particulate consists of the metal *oxide* compounds, which are heavier than just their metal components. In addition, fluxing material components, such as calcium, sodium, and potassium salts were not analyzed for, nor were the residues of any organic components that might have been present in fluxing materials. Tables 1 through 4 in Appendix F show all of the gravimetric data corrected for blank weight loss (see Notes on Tables 1-4 for explanation of corrections). Also, it can be seen in Table 6-1 (bottom row) that the ratio of emissions from stick (i.e., rod) welding (performed essentially only at SWRMC) to wire welding is about 4.5:1 for the metal analysis data, and about 9.0:1 for gravimetric data. The reason for the greater emissions from stick welding is that the rods are covered with a significant coating of calcium-based flux materials. Such flux materials do not exist in wire welding (with the possible exception of flux-core wire). These calcium compounds clearly contribute significantly to particulate emissions.

Metal analysis data tables for the cascade impactor (CI) sampling can be found in Appendix H. There are four sets of data, one for each facility sampled. Each set of data has a separate sheet for each sampling run. The values shown are in micrograms (µg) of each metal on each of the nine CI stages. Each data set has been corrected for blanks by subtracting average blank values. Where such subtractions yielded negative values, those negative values were assigned the value of 0.00 µg. These negative values occur when an undetected tiny tear occurred on the filter or filter fibers and fragments were left in the impactor. The data do NOT include the metals aluminum, barium, and zinc; see Section 6.1.1.1, *Particulate/Metal Data*, for the explanation. In addition, the right side of each sheet of Appendix H contains a table of emissions of each metal relative to actual weld time (i.e., while an arc was struck), and relative to the amount of wire or rod used.

6.1.1.2 Industrial Hygiene Data. Composite industrial hygiene (IH) data are shown in Table 6-2. This table compares the highest average weekly values (averages of the values for each day of the sampling week) encountered for each metal component. It also shows the highest individual daily value encountered. (The highest daily values occur within the highest average week.) Table 6-2 also compares the measured values to the NIOSH and OSHA TWAs, where available. Measured values exceeding either TWA are shown in bolded, large, red font, along with the relevant information on the type of alloy being welded. Also, the IH appendix (Appendix I) shows bar charts for hexavalent chromium, copper, manganese, and nickel for days where there were runs that were conducted while welding chromium-containing alloys (HY-80 and Cr-Mo). These charts graphically display IH emission concentrations (near and far from the welder) as compared to OSHA standards. Note that IH samples were taken only once for an entire day (in two different locations – one near the welder, and one about 10 feet away, as a background). The same type of welding was almost always performed in a given day (i.e., PPI or conventional pulsed power), but not necessarily with the same metal plate or wire/rod alloys. In any case, it can be seen that hexavalent chromium (Cr^{+6}) concentrations averaged about half of the recently promulgated standard (71 FR 10100 – 28 Feb 2006) of 5.0 µg/m^3 for a week during which chrome-molybdenum (Cr-Mo) was welded. During one of the days of that week, however, the Cr^{+6} concentration was almost twice the proposed standard.

There were small exceedences of the OSHA copper standard (and NIOSH recommended TWA) during welding mild steel while using both mild steel and Cr-Mo welding wire. The origin of the copper is probably from the copper-coated welding wire.

There was also one slight exceedence of the NIOSH-recommended TWA of 0.015 mg/m^3 (but not the OSHA TWA of 1.0 mg/m^3) for nickel while welding during a day where both mild steel and armor plate were being welded.

Attached, in Appendix I. Figures I-5 through I-12, are "pie" charts showing the typical mix of metals collected on the IH samplers that were positioned near the welder (about two feet). Typically, over 80% of the metal found in the IH samples is (not surprisingly) iron. These charts *exclude* iron, so that the other metals are better presented. (Note that on the lower left corner of each chart, the percent of iron is shown for the reader's reference. Iron ranged from 55 % – 91 %.) Other than iron, in almost all cases, manganese is the predominant metal in the IH samplers (as it was in the in the cascade impactor samples), ranging from 3.25 to 14.1%. Magnesium is present (also as it was in the in the CI samples) from 0 to 4.5%. Copper is present from 0.26 to 1.8%. Nickel is present from 0 to 2.1%. Total chromium was present from 0.18 to 0.81%. Aluminum and zinc also appear to be present at significant levels in all of the samples. However, it is believed that these are primarily artifacts of the metal content in the blank IH filters, even though blank metal content was subtracted. Most blank IH filters had aluminum and zinc contents in the same order of magnitude as the metal particulate loading. There is some evidence in the literature that aluminum is present in flux core wire welding [FCAW] [16].

There is no obvious difference in the mix of IH metal emissions between PPI and conventional pulsed power welding at a given facility.

In Section 6.1.1.1, for environmental samples (i.e., samples withdrawn from the ventilation duct), it was noted that where chromium emissions were present in measurable quantities (while welding Cr-Mo at SWRMC), the ratio of hexavalent chromium to total chromium was much higher for "stick" welding than for wire welding. Not surprisingly, this same phenomenon is true for the IH samples. Specifically during *wire* welding, the average value of about 0.7% of the total chromium emissions was hexavalent chromium, with range of 0.0 to 1.6%. During *"stick"* welding, hexavalent chromium averaged 26.7% of total chromium, with a range of 9.1 to 47.9%). (See data tables in the back of the IH data tables, Appendix I.)

Ultraviolet (UV) radiation was measured with continuous emissions monitors (CEMs). Unlike the gas concentration measurements logged by the CEMs (i.e., CO, NO_x, and O_3), which changed relatively gradually, UV radiation is instantaneous during welding operations, and immediately drop, essentially to zero, when welding ceases. Because of this rapid change the most accurate monitoring occurred when at SWRMC, where UV measurements were recorded every 15 seconds. UV was recorded only once per minute at PSNSY. The equipment used at ANAD and MCLB was overwhelmed by the welding arc and the output was unusable. It can be seen from the SWRMC graphs in the CEM appendix (Appendix G, first four pages), that maximum values for UV during welding operations averaged about 4 watts/cm^2 during whole data collection period period. *Note that the values for UV on the SWRMC graphs' y-axis are 10-times higher than their true value in order to accommodate them in a meaningful way on the same graph that displays* NO_x, *and* O_3. *Hence, a y-axis value for UV of 40 is actually 4 watts/cm*^{2}. Values for UV radiation on the graphs for PSNSY have values in the 300 – 400 watts/cm^2 range. *Note again, that the values for UV on the PSNSY graphs' y-axis are 0.1-times as great as their true value in order to accommodate them in a meaningful way on the same graph that displays* NO_x, *and* O_3. *Hence, a y-axis value for UV of 40 is actually 400 watts/cm*^{2}. It is unclear why UV values at PSNSY appear to be about 100 times higher than they are at SWRMC. The UV sensor may have been located significantly closer to welding operations at PSNSY than at SWRMC (theoretically, radiation intensity varies in inverse proportion to the square of the distance from the source); however, the operation of the UV monitor was more erratic (i.e., less reliable) at PSNSY than it was at SWRMC, such that the values at SWRMC are believed to be more representative of actual exposure. The SWRMC graphs show that UV radiation may be higher during PPI *wire* welding than with conventional pulsed power "*stick*" welding, about 5 watts/cm^2 rather than 4 watts/cm^2. If there is a difference between conventional pulsed power *wire* welding and PPI *wire* welding UV radiation, it is much more difficult to determine (see Appendix G graphs for PSNSY).

In any case, any differences in UV exposure between conventional and PPI welding, whether stick or wire become academic because a welder with normal PPE (i.e., gloves, long sleeves, face shield) should not be in danger of excessive UV exposure. An evaluation focusing exclusively on UV exposure should be conducted to fully evaluate worker exposure.

6.1.2 Weld Quality Data. Weld quality data are summarized in Table 6-3 at the end of Section 6. At least two test plates were evaluated for each of the four involved facilities. In general, the weld quality of Pulsed Power Inverter welds, in terms of tensile yield strength, ultimate tensile strength, percent elongation, and CVN appear to be equivalent to conventional pulsed power techniques.

Specifically, for those test plates that were welded according to Military Specifications (MILSPECS) or American Welding Society (AWS) specifications, usually met tensile yield strength and ultimate tensile strength requirements. Those requirements are shown in Table 6-3 in the shaded rows under the appropriate column heading. The values in the row above the shaded row are the actual test value. (For instance, for the ANAD Pulse 2 test, minimum tensile yield strength of 68 kips per square inch [ksi] was required. The actual test showed a 85 ksi strength. The ultimate tensile strength requirement for the same plate was 80-100 ksi. The test plate passed with a 95 ksi ultimate tensile strength.) All tests plates except for SWRMC Test 4 passed the percent elongation requirements. (For SWRMC Test 4, only 14% elongation was achieved versus a requirement of 19 %.) For those plates with specifications for Charpy V-Notch (CVN) strength at various temperatures, all test plates passed. (For example, for the ANAD "Conv 1" test, the specification requires that the energy absorbed prior to fracture of the weld joint at -40ºF be at least 20 foot-pounds. The actual weld was tested at –45ºF [a more rigorous temperature than the required -40ºF], and achieved an energy absorbed prior to fracture value between 29 and 47 foot-pounds.) It should be noted that many of the plates tested did not have any MILSPEC or AWS requirements for some of their properties.

Table 6-1: Metal Emissions and Total Particulate Emissions Relative to Quantity of Wire/Rod Used

(All values in mg of emission per gram of wire or rod used)

Facility (and Wire or Rod)	Metal Analysis Data (mg/gram)	Gravimetric Data (mg/gram)	Ratio of Gravimetric/Metal
MCLB - Wire	1.6	4.3	2.7
ANAD - Wire	2.2	6.2	2.8
PSNSY - Wire	1.8*	4.8	2.7
SWRMC - Wire	1.9	5.3	2.8
- Rod	8.5	47.0	5.5
Averages - Wire	1.9	5.2	2.75
- Rod	8.5	47.0	5.5
Rod/Wire Emission Ratios	4.5	9.0	

* Does not include data for 2nd week, metal analytical data believed to be suspect.

Table 6-2. Industrial Hygiene Sampling Metal Data Compared to NIOSH and OSHA Standards
(All values in mg/m³; all values for metal dust/fume unless otherwise noted)

Metal	ACGIH TLV (2007)	NIOSH REL TWA [1]	OSHA PEL TWA [2]	High Avg. Weekly Value	Highest Daily 8-Hr Value
Aluminum	10 (as AlO)	5 (respirable)	5 (respirable)	0.033	0.643 (while welding Al)
Antimony	0.5	0.5	0.5	0.00005	-
Arsenic	0.01	0.002	0.010	0.00012	0.00049
Barium	0.5	0.5 (for BaCl2 & $BaNO_3$)	0.5 (for BaCl2 & $BaNO_3$)	0.0022	0.0079
Beryllium	0.002	0.0005	0.002	<0.000001	-
Cadmium	0.002 (Compound)	None	0.005	0.0000047	-
Total Chromium	0.5 (as metal)	0.5	1.0	0.00423	0.013
Hexavalent Chromium[3]	0.01 (insoluble)	0.00052[4]	0.0050	0.00259	***0.0086 (SWRMC, Cr-Mo, non-pulsed)***
Cobalt	0.02	0.05	0.10	0.00006	-
Copper	0.2 (as fume)	0.01	0.01	0.0116	***0.031 (SWRMC, mild steel w/ & w/o Cr-Mo wire, PPI)***
Iron	5	5	10	0.824	-
Lead	0.05	0.05	0.05	0.00062	0.0013
Magnesium	10 (as MgO)	None	15 (as MgO)	0.0039	-
Manganese	0.2	1.0	5.0	0.112	***0.146***
Molybdenum	3 (resp fraction)	None	15	0.0029	-
Nickel	0.2 (insoluble)	0.015	1.0	0.0120	***0.0163 (ANAD, mild steel & armor plate, non-pulsed)***
Selenium	0.2	0.2	0.2	<0.0003	-
Silver	0.01 (insoluble)	0.01	0.01	0.00009	-
Strontium	0.0005 (as Cr)	None	None	0.00036	-
Vanadium	0.05	0.05	0.01 (as V2O5)	0.00038	-
Zinc	2 (as ZnO)	5 (as ZnO)	5 (as ZnO)	0.058	0.166

[1] NIOSH REL A time-weighted average (TWA) concentration that NIOSH recommends not be exceeded for up to a 10-hour workday during a 40-hour workweek.
[2] OSHA PEL A time-weighted average (TWA) concentration that OSHA recommends not be exceeded for up to 8-hrs during a workday.
[3] The hexavalent chromium values reported in this table reflect regulatory and advisory values during the testing period. The OSHA PELs changed in 2006.
[4] Hexavalent chromium values reported here are for hexavalent chromium, and not chromium oxide.

Table 6-3: Weld Quality Data

Facility	Weld ID/ Joint	Welding Process/ Position	Base Plate/ Thickness	Welding Electrode	Specification	Tension Test Type	Tensile Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation, %	Reduction of Area, %	CVN Temp, F	CVN Energy, ft-lb
Marine Corps Logistics Base [5]	T3 Single bevel	GMAW-P Vertical	Armor Plate 0.25" ***	MIL-100S-1		Flat Transverse **		60	4.3	26.1	-60 0	37, 41, 42 * 44, 46, 49 *
					MIL-E-23765/2						-60 0	35 60
Marine Corps Logistics Base	T7 Single bevel	GMAW-P Vertical	Armor Plate 0.25" ***	MIL-100S-1		Flat Transverse **		123	6.5	26.9	-60 0	28, 32, 34 * 36, 37, 40 *
					MIL-E-23765/2						-60 0	35 60
Anniston Army Depot	Conv1 K joint	FCAW Vertical	OS 1"	E81T1-Ni2		0.350" diam	79	92	26.5	66.4	-45	29,34,45,46,47
					AWS A5.29		68 min	80 - 100	19 min	---	-40	20
Anniston Army Depot	Pulse2 K joint	FCAW Vertical	OS 1"	E81T1-Ni2		0.350" diam	85	95	19.3	54.9	-45	46,54,54,55,64
					AWS A5.29		68 min	80 - 100	19 min	---	-40	20
Puget Sound Naval SY	HY-PT14	GMAW-P Vertical	HY-80	MIL-100S-1		0.350" diam	90	113	23.2	70.4	-60 0	65, 82, 94 100, 112
					MIL-E-23765/2		82 - 120	---	16 min	---	-60 0	35 60
Puget Sound Naval SY	HY-PT16	GMAW-P Flat	HY-80	MIL-100S-1		0.350" diam	95	107	23.6	71.5	-60 0	78, 100 127, 134
					MIL-E-23765/2		82 - 120	---	16 min	---	-60 0	35 60

[5] Shaded are indicates the Specification's standard value for comparison to the test results.

Table 6-3: Weld Quality Data (continued)

Facility	Weld ID/ Joint	Welding Process/ Position	Base Plate/ Thickness	Welding Electrode	Specification	Tension Test Type	Tensile Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation, %	Reduction of Area, %	CVN Temp, F	CVN Energy, ft-lb
Puget Sound Naval SY	T#2	FCAW	OS	E81T1-Ni2		0.350" diam	75	89	24.3	67.0	-20	62, 66
											0	127, 134
					AWS A5.29		68 min	80 - 100	19 min	---	-40	20
Southwest Regional Maintenance Center - San Diego	Test 4 B1V.1	GMAW-P	4130 (Cr-Mo) 3/8"	ER80S-B2		0.252" diam	94	110	14	31		
					AWS A5.28		68 min	80 min	19 min		---	---
Southwest Regional Maintenance Center - San Diego	Test 7	SMAW	4130 (Cr-Mo) 3/8"	E9018-B3L		0.252" diam	102 100	118 116	26 25	67 64		
					AWS A5.5-81		77 min	90 min	17 min	---	---	---

* Sub-sized CVN Specimens.

** Transverse tensile - no specification requirements

*** Base plate is not typical; welded using MCLB SOP; weld metal properties are for information only.

7.0 COST ASSESSMENT

7.1 COST MODEL

Elements that contribute to developing a cost analysis of Pulsed Power Inverter (PPI) use versus conventional power sources are as follows:

- capital cost of the units,
- labor hours required to produce a specific length of weld (with all other parameters kept the same),
- electrical costs associated with a specific length of weld, and
- cost of the welding wire associated with a specific length of weld.

These elements do not lend themselves to a full economic analysis such as those found in ***Environmental Cost Analysis Methodology (ECAMS) Handbook***. Therefore, a simple cost comparison is presented below.

The cost savings implications of PPI's reported ability to lessen environmental and health impacts of welding could be significant. It is estimated that meeting a Cr^{+6} standard of 5 $\mu g/m^3$ will cost about $5 million to implement (i.e., capital cost) and $36 million annually in Navy ship construction alone in the USA. The cost implications for welding in other DOD venues would be similarly high. [9][10][11]

7.2 COST ANALYSIS AND COMPARISON

Capital cost of the welding equipment for the purchased PPI systems (power source, wire feeder and torch) are in the $6k to $8k price range. One system with sophisticated computer software required an additional $2,000. A complete system with consumables for a month of testing and training ranged between $8.2k and $13.4k depending on the geographic location, spare parts on hand, working agreements with vendors and other site needs. Vendor provided software training ranged from free to $2000 for two days. This fee depended on prior arrangements the vendor already had with the facility. To replace an existing conventional system would require an investment of approximately $6k to $8k (2003/2004 costs) excluding consumables assuming the existing system is scrapped. New conventional systems are approximately $1000 to $2000 less expensive. Table 7-1 summarizes the actual equipment and consumables cost for each facility. Large scale purchases and Government Services Administration (GSA) pricing could further reduce the costs for new equipment. Consumable costs will be far less expensive when purchased in bulk and through an ongoing contractual relationship. Purchases for this project were a one time event.

Table 7-1: Summary of Equipment Costs (2002/04 basis)

Activity/ Source	Item	Source	Model	Project Cost ($)
ANAD Anniston, AL	Power Source	Miller	456MP	$4,188
Southern Welding Supply	Wire Feeder	Miller	S-74 DX	$1,621
Birmingham. AL	Weld Gun	Binzel	501D	$353
ANAD Total				**$6,162**
MCLB Albany, GA	Power Source	Miller	456MP (later switched to 456P)	$4,282
Jones Welding	Wire Feeder	Miller	60M and HP251D-1	$2,512
Albany GA	Weld Gun		400 AMP MIG gun & lead	$393
MCLB Total				**$7,187**
PSNSY, Bremerton, WA	Power Source	Lincoln	Powerwave 455/SST	$6,166
Praxair	Wire Feeder	Lincoln	Wire feeder 10 Dual	$2,533
Seattle, WA	Control Panel	Lincoln	SST & Pulse Panel	$647
	Weld Gun	Magum	400-0.035-0.045 & .052 1/16"	$330
	Software	Lincoln	Wave Designer Pro	$1,025
PSNSY Total				**$10,701**
SWRMC, San Diego, CA	Power Source	Miller	Invision 354MP/460 MIG Runner	$5,782
(formerly SIMA)	Wire Feeder	Miller	70 Series/24V Feed incl. in quote above	$0
Welders Supply & Equip, San Diego, CA	Weld Gun		Gooseneck, jacketed 4.5 " 50 deg wrench swivel	$64
SWRMA Total				**$5,846**

7.3 COST BASIS

The cost of the welding wire, per length of weld is the same for either technology (i.e., the same wire is typically used with either technology), except when SMAW (stick) was used. The amount of wire for a specific weld length will not change significantly between technologies, even if one technology is faster (per length of weld). Consequently, the cost of wire associated with each technology is the same. For our tests, wire costs in 2002-2004 dollars are listed below. Some facilities provided all or part of the wire used during testing and we do not have the cost for those items. Bulk purchases will be considerably less than the single spool cost purchased for this demonstration.

Table 7-2: Costs for Welding Filler Material (Wire)

Filler Metal	Cost/ Spool	Location	Year ordered
CN LA-100 60lb, 1/16" Dia	$171	ANAD, Anniston AL	2003
EH100S-1 60lb., 0.045 Dia	$482	MCLB, Albany GA	2003

Activity provided		PSNSY, Bremerton, WA	2003
ESAB Spoolarc 95, 35 lb, 0.035 Dia	$210	SWRMC San Diego	2004
ESAB Spoolarc 95, 35 lb, 0.045 Dia	$188	SWRMC San Diego	2004
Techalloy 80S-B2, 30 lb, 0.035 Dia	$147	SWRMC San Diego	2004
Techalloy 80S-B2, 30 lb, 0.045 Dia	$147	SWRMC San Diego	2004

Directly measuring power output of each piece of equipment was unsuccessful. Given the nature of the field operations, we were unable to isolate the equipment's power usage, from the general power grid. Since part of participant's compensation for participating in the study was to receive the demonstrated equipment, the team was unable to splice into the power cord to install power measurement equipment without destroying the equipment warranty.

Energy costs were generated from machine read-outs for voltage and amperage when an arc was struck. The goal of the MCLB test was to determine the limit of detection (LOD) for welding fume verses arc time. As testing proceeded and data was evaluated more detailed parameters were recorded. Arc time, in seconds, was rigorously recorded at PSNSY and SWRMC. Average electrical energy costs were taken from the Defense Utility Energy Reporting system [19]. US Army energy usage was estimated using southeastern US Navy facility reports. Hourly wages were estimated using Bureau of Labor Statistics data for welders [20]. Apprentice rates were used for PSNSY and ANAD. The upper end of the rating scale was used for PSNSY and MCLB. This reflects the actual welders conducting the demonstration.

7.4 LIFE CYCLE DRIVERS

Table 7-3 shows the average power usage to weld a 12-inch plate and results were mixed. In some cases the PPI machine required less power and in other cases the conventional process required less power. Where power efficiency improved with the use of PPI, differences were insufficient to provide a useful payback.

Table 7-3. Average Power Usage

Facility	Non-pulse Process	Steel	Pos'n	Pulsed Energy Use (GMAW)	Conventional Power Use (kW)	Percent Change, PPI vs Conv
MCLB	GMAW	Armor	Flat	5.9	3.5	+59
PSNSY	FCAW	OS	Flat	-	5.8	na
PSNSY	FCAW	OS	Vert	4.4	6.2	-29
PSNSY	FCAW	HY-80	Flat	4.6	-	na
PSNSY	SMAW	HY-80	Vert	3.4	3.9	-13
SWRMC	SMAW	Cr-Mo	Flat	6.0	4.4	+27
ANAD	FCAW	OS	Flat	6.0	5.6	+7

Table 7-4 compares productivity and energy costs for three of the four field sites. Efficiency calculations were not collected at MCLB since the test goal was to determine arc times necessary to generate enough emissions to exceed the environmental, safety and occupational health analytical LOD. Formulas used to derive values in Table 7-4 are listed below:

- Deposition Rate (%) = Ratio of arc time (sec) to welding time (sec) for the specific test plate
- Annual Productivity (Hours) = Deposition Rate (%) x 1248 (hours) (See note 2 on table)
- Annual Personnel Cost ($) = Annual productivity (hours) & Bureau of Labor Statistics (BLS) Salary ($/hour)
- Annual Energy Cost ($) = Machine Power Usage (kilowatts) x regional rate/1000 ($/megawatt hours) x annual productivity (hours)

When efficiency calculations are evaluated power usage and personnel time becomes even more unclear. This technology cannot be recommended based on the two weeks of testing performed at each facility.

With respect to the amount of time it takes to make a given length of weld, there is a considerable reduction in weld time when compared to SMAW (stick welding) at SWRMC, San Diego. This time reduction is a well-documented cost savings and cannot be attributed to PPI technology. In addition, SMAW is frequently used when there is limited access or for quick repairs since the machine is portable and no external shielding gas is required. Substituting GMAW for SMAW is not an option in these cases.

In some cases, pulsed power inverters seem to produce an increase in welder productivity. However, our two week sample at each site was insufficient to reflect a true annual payback. Overall welder productivity is affected by variables such as welder skill, process, set-up, housekeeping, training, medical appointments, other workplace distractions, and even vacation and sick leave. During this study, when the welder was actually welding, typical efficiency or deposition rate (arc time verses weld time) ranged from 19% to 50%.

Welders join individual pieces more quickly with PPI. However, cooling and grinding techniques were different from day to day during the two weeks of testing. They may be able to produce more welds in a given day. However, it is difficult to determine if the overall welding (not only arc) time is quicker at each location. More welds per day could translate into higher exposure and environmental emissions since workers are more efficient. A long term test would be required by each facility manager to determine if this hypothesis is correct.

Table 7-4: Labor and Electrical Cost Data

Date	Metal	Plate # Vertical vs. Flat	Pulse Yes vs. No	Process	Machine Energy Usage (kW) [21]	Arc Time (Sec)	Deposit Rate (D) % *(Note 1)*	Annual Productivity (Hr) *(Note 2)*	Annual Personnel Cost [20]	Annual Energy Cost [19] ($/MWhr) *(Note 3)*
Marine Corps Logistics Base (MCLB), Albany, GA										
Local Costs Basis (Master Welder Hourly Rate & Energy = $/MWhr) *(Note 4)*									$18.05/hr	$52.99
Efficiencies not evaluated for MCLB. Focus was on environmental and OSH results										
Anniston Army Depot (ANAD), Anniston, AL										
Local Costs Basis (Apprentice Welder Hourly Rate & Energy = $/MWhr) *(Note 4)*									$14.72/hr	$59.31
10/27/03 R1	OS	1C/F	N	FCAW	5.6	1303	0.09	118	$1,734.55	$39.22
10/27/03 R2	OS	P1 & Bead	Y	FCAW	5.6	936	0.10	130	$1,910.54	$24.49
10/28/03 R1	OS	P1/F	Y	FCAW	6.1	1555	0.43	539	$7,935.06	$110.65
10/28/03 R2	OS	P2/F	Y	FCAW	6.0	2175	0.46	578	$8,501.27	$117.18
10/28/03 R3	OS	P3/F	Y	FCAW	6.3	944	0.15	187	$2,752.67	$39.72
10/29/03 R1	OS	P3/F	Y	FCAW	6.2	1372	0.38	476	$7,001.22	$98.76
ANAD electrical cost taken from an average several southeastern DON activities										
Puget Sound Naval Shipyard (PSNSY), Bremerton, WA										
Local Costs Basis (Apprentice Welder Hourly Rate & Energy = $/MWhr) *(Note 4)*									$14.72/hr	$33.62
08/10/04	OS	1/V	N	FCAW	6.59		*0.32*	399	$5,878.58	$88.47
08/10/04	OS	2/V	N	FCAW	5.79		*0.32*	399	$5,878.58	$77.74
08/12/04	HY-80	7/V	N	SMAW	3.6	3028	0.32	399	$5,878.58	$48.87
08/12/04	HY-80	8/V	N	SMAW	4.1	2202	0.31	387	$5,694.87	$53.69
08/19/04	OS	17/F	N	FCAW	5.48	1203	0.49	612	$9,001.57	$112.65
08/19/04	OS	18/F	N	FCAW	6.04	903	0.50	624	$9,185.28	$126.65
08/11/04	OS	3/V	Y	GMAW	4.35		0.25	312	$4,592.64	$45.66
08/11/04	OS	4/V	Y	GMAW	4.35		0.32	399	$5,878.58	$58.40

Table 7-4: Labor and Electrical Cost Data (continued)

Date	Metal	Plate # Vertical vs. Flat	Pulse Yes vs. No	Process	Machine Energy Usage (kW) [21]	Arc Time (Sec)	Deposit Rate (D) % *(Note 1)*	Annual Productivity (Hr) *(Note 2)*	Annual Personnel Cost [20]	Annual Energy Cost [19] ($/MWhr) *(Note 3)*
08/13/04	OS	5/V	Y	GMAW	4.35	957	0.24	300	$4,408.93	$43.83
08/16/04	HY-80	11/V	Y	GMAW	3.69	693	0.32	399	$5,878.58	$49.48
08/16/04	HY-80	12/V	Y	GMAW	3.30	781	0.32	399	$5,878.58	$44.30
08/17/04	HY-80	13/V	Y	GMAW	3.54	1262	0.26	324	$4,776.35	$38.58
08/17/04	HY-80	14/V	Y	GMAW	3.48	911	0.52	649	$9,552.69	$76.00
08/18/04	HY-80	15/F	Y	GMAW	4.58	1032	0.32	399	$5,878.58	$61.52
08/18/04	HY-80	16/F	Y	GMAW	4.56	1205	0.16	200	$2,939.29	$30.60
Derived Value based on similar work										
Southwest Regional Maintenance Center (SWRMC), San Diego, CA										
Local Costs Basis (Master Welder Hourly Rate & Energy = $/MWhr) *(Note 4)*									$18.05/hr	$122.76
10/04/04 AM	Cr Moly	1/F	Y	GMAW	6.05	819	0.23	285	$4,188.49	$57.86
10/04/04 AM	Cr Moly	2/F	Y	GMAW	6.75	886	0.25	307	$4,519.16	$69.70
10/04/04 PM	Cr Moly	3/F	Y	GMAW	5.83	926	0.23	287	$4,225.23	$56.30
10/05/04 AM	Cr Moly	4/F	Y	GMAW	5.57	946	0.26	328	$4,831.46	$61.42
10/05/04 AM	Cr Moly	5/F	Y	GMAW	5.90	808	0.22	280	$4,115.01	$55.47
10/05/04 PM	Cr Moly	6/F	Y	GMAW	6.00	771	0.21	267	$3,931.30	$53.91
10/06/04AM	Cr Moly	7/F	N	SMAW	4.37	1634	0.30	378	$5,558.80	$55.44
10/06/04AM	Cr Moly	8/F	N	SMAW	4.40	1321	*0.30*	374	$5,511.17	$55.44
10/07/04AM	Cr Moly	9/F	N	SMAW	4.48	1379	*0.30*	374	$5,511.17	$56.39
NOTES:										

Table 7-4: Labor and Electrical Cost Data (continued)

Date	Metal	Plate # Vertical vs. Flat	Pulse Yes vs. No	Process	Machine Energy Usage (kW) [21]	Arc Time (Sec)	Deposit Rate (D) % *(Note 1)*	Annual Productivity (Hr) *(Note 2)*	Annual Personnel Cost [20]	Annual Energy Cost [19] ($/MWhr) *(Note 3)*
(1) D = Ratio of Arc hours to Welding hours for welder (%). Note D is different than formula defined in AWS. *Italicized values* are estimates derived from field data sheets										
(2) Typical productivity = welder arc time: welding work time. [Assumes a welding work year is 2080 work year X.0.6 (for leave -vacation/sick, training, administrative duties, medical, housekeeping) = 1248 hours]										
(3) Idle voltage and amperage also contribute to annual costs but not considered here.										
(4) Welder Rates from BLS/Welding Workers. ANAD & PSNSY were assumed to be median salary and MCLB & SWRMC high end of median.										

8.0 IMPLEMENTATION ISSUES

8.1 ENVIRONMENTAL CHECKLIST

Both PPI and conventional pulsed power welding, *when properly ventilated*, will comply with recently promulgated OSHA regulations for Cr^{+6}, as well as for CO, O_3, and NO_x. While PPI welding appears to generate slightly more UV radiation than conventional welding, a welder with normal PPE (i.e., gloves, long sleeves, face shield) should not be in danger of excessive UV exposure. If the area of welding is *not* ventilated (or the welder is not supplied with external clean air) it is possible that there will be excessive exposure to particulates in general, and possibly to hexavalent chromium, copper, and nickel in particular, in excess of OSHA or NIOSH limits, for both PPI and conventional pulse power welding operations. In addition, exposure to O_3 may also be an issue.

8.2 OTHER REGULATORY ISSUES

EPA does not specifically regulate Cr^{+6}, other metals, CO, O_3, or NO_x emissions from welding operations. Currently there are no EPA-driven regulatory requirements for either PPI or conventional pulsed power welding operations. However, each of these components will contribute to ambient exposure, and overall facility fugitive emissions. There are indications that EPA will begin regulating welding operations using the Residual Risk Provisions in the National Emission Standards for Hazardous Air Pollutants (NESHAP): Shipbuilding and Ship Repair (Surface Coating) Operations. The additional regulations will directly affect contractors building naval ships and larger vessels used by other services, e.g. the Army and Coast Guard. This practice will also affect shipyard repair operations that take place on DOD property and in contractor shipyards. Since the EPA is expanding the regulation beyond coatings and including welding they are setting a precedent. DOD should watch the progress of the NESHAP Defense Land Systems and Miscellaneous Equipment Surface Coating Rule and anticipate regulatory creep.

The results of this demonstration do not indicate a significant difference for any of the emissions studied between PPI and conventional pulsed power welding.

8.3 END-USER ISSUES

A bead of filler material can be laid down faster with the pulsed power inverter when compared with the conventional welding process. Therefore, the welder could potentially produce more work in a day. This is one of the marketing advantages mentioned by the vendors. By producing more work, the welder could potentially increase exposure, even though the test scenario produced similar amounts of emissions.

All welders said they felt comfortable with the PPI equipment after using it for a couple days, and believed they could produce better welds. No additional supplies or hardware are needed to operate the PPI equipment in comparison to conventional equipment.

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APPENDICES

Appendix A: Points of Contact

POINT OF CONTACT	ORGANIZATION Address	Phone E-mail	Role in Project
Kathleen Paulson	NAVFAC ESC/EV 421 1100 23rd Street Port Hueneme, CA 93043	805/982-4984 805/982-4832 kathleen.paulson@navy.mil	Principal Investigator
Jill Hamilton	NFESC/NAVOSH (ESC 4 1100 23rd Street Port Hueneme, CA 93043	805/982-4892 jill.hamilton@navy.mil	NFESC- Logistics and Planning
Gene Franke	NAVAL SURFACE WARFARE CENTER Carderock Division, Welding Engineering Bethesda, MD, 20817	301/227-5576 frankegl@nswccd.navy.mil	Principal Investigator
Stephen Schwartz	Versar, Inc. Springfield, VA 22151	703/642-6787 schwaste@versar.com	Environmental & OSH Contractor
Chris Downing	ANNISTON ARMY DEPO (ANAD), Weld Certificatio AMSTA-AN-PEWL Anniston, AL, 36201	256/310-8099 downingc@anad.army.mil	Anniston- Facility Coordination
Ken Reid	ANAD AMSTA-AN-PE Anniston, AL, 36201	256/235-7515 reidk@anad.army.mil	Anniston- Logistics
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Bill Baker	MCLB, Maintenance Dire Welding Engineering Albany, GA, 31704.-	229/639-6952 bakerwg@logcom.usmc.mil	Albany- Logistics
Dale Frei	PUGET SOUND NAVAL SHIPYARD (PSNSY), Welding Engineer Bremerton, WA, 98314	360/476-2528 freid@psns.navy.mil	Puget Sound-Facility Coordination
Randy Kessler	PSNSY, Welding Equip. M Bremerton, WA, 98314	360/476-2528 kesslerr@psns.navy.mil	Puget Sound-Facility Coordination
Mike Maloney	SOUTHWEST REGIONA MAINTENANCE CENTEF (SWRMC), San Diego, CA 92136	619/556-2915 michael.p.maloney@navy.mil	San Diego-Facility Coordination
Marvin J. Speck	SWRMC, Welding Engr. San Diego, CA, 92136	619/556-6523 marvin.speck@navy.mil	San Diego-Facility Coordination
Charles Kubrock	ANALYTICAL LABORATORY, NEPMU Naval Station, San Diego, CA 92136	619/556-1427 cakubrock@nepmu5.navy.mil	Analytical Lab Analysis
Robert Weber	USACE CERL PO Box 9005 Champaign IL 61826-900	217-373-7239 Robert.A.Weber@erdc.usace.army	Welding Engineer QA/QC
Bhaskar Kura	University of New Orleans	(504) 390-9405 BKura@uno.edu	Envi Engr, QA/QC

Appendix B
Analytical Methods Supporting the Experimental Design

Particulate Stack Sampling

Samples were extracted from the 12-inch diameter welding fume ventilation duct using a modified EPA Method 5 stack sampling train. The aim of each sample run was to capture emissions from at least 40 minutes of actual welding time. Forty minutes of welding arc time was determined to be the minimum amount of time needed to collect sufficient material on most filters and detect that material above the analytical limit of detection. The sampling train consisted of: an Andersen Mark III, 8-stage stainless steel cascade impactor (which had a pre-separation stage and a final filter stage); and a series of four iced impingers. The first two impingers were filled with 100 ml of de-ionized water; the third impinger was empty, and the last impinger had about 200 grams of silica gel. (The sole purpose of the impingers was to determine the moisture content of the air stream being sampled).

Because the 12-inch PVC exhaust duct used for sampling was relatively small, especially in comparison to the cross section of the impactor, the impactor inlet was placed and secured at a position that represents the average flow velocity through the duct (based on preliminary pitot-tube measurements). The inlet flow to the sampling train was adjusted as well as possible to the average exhaust duct velocity, given the impactor's requirement for a specific optimum volumetric flow range.

Filter media for each stage of the cascade impactor (glass fiber filter media) were desiccated and pre-weighed before sampling. After sampling, each filter was desiccated again and then reweighed. All weight changes were recorded. Any contents of the pre-separation section of the impactor were discarded. After all filter weighing was complete, the filters were placed in individual petri dishes and sent to a laboratory for metalic analysis.

Prior to analysis of the filter media from each stage of the impactor, the analytical laboratory cut each filter media in half. One of the halves was analyzed using OSHA Method ID-215 [B-1] (extraction in an aqueous solution followed by ion chromatography). The other half of each filter media was analyzed using NIOSH method 7300 [B-2], (inductively coupled plasma/atomic emissions spectroscopy – ICP/AES).

Industrial Hygiene Sampling for Metals

Four each 2.0 – 2.1 liter per minute industrial hygiene samples were taken during each sampling day. The intakes for two samplers located side by side at about one foot from the welding operation. These samplers are identified as near-filed. The other two samplers were placed together at about 10 feet from the welding operation and identified as far-field. All samples were engineering (also called area) samples and no personnel samples were taken because the demonstration's focus was to compare

[B-1] OSHA Sampling and Analytical Methods, Hexavalent Chromium In Workplace Atmospheres http://www.osha.gov/dts/sltc/methods/inorganic/id215/id215.html *(accessed 2/4/2010)*
[B-2] CDC/NIOSH Manual of Analytical Methods, Method 7300, Elements by IPC (Nitric/Perchloric Acid Ashing) http://www.cdc.gov/niosh/docs/2003-154/pdfs/7300.pdf (*accessed 2/4/2010*)

emissions before and after applying the engineering control, the PPI machines. No All samplers were run continuously for eight hours, or until they could no longer draw the required volume of air (due to blinding of the sampler filters).

One of the samplers at one-foot from the welding operation, and one of the samplers at the 10 foot location drew gases through a polyvinyl chloride (PVC) cassette-type filter prescribed by OSHA Method 215, for hexavalent chromium. The other sampler at each of the two locations contained a NIOSH Method 7300 mixed cellulose ester (MCE), 0.8-μm pore size, filter for monitoring all other metals, including total chromium. In addition, a blank PVC and MCE filter were sent for analysis weekly, and used as a background control sample.

The PVC Method 215 filters were analyzed using the OSHA Method ID-215 technique (extraction in an aqueous solution followed by ion chromatography). The MCE filter media were analyzed using the NIOSH method 7300 technique, (inductively coupled plasma/atomic emissions spectroscopy – ICP/AES).

CEM for NO_x:

A Thermo Model 42 CEM or an Advanced Pollution Instrumentation Model 200A was used to monitor NO_x, in a range of 0-100ppb. The inlet tube to the instrument was positioned inside the exhaust duct, in order to obtain maximum values along with less random, wind-caused variability. It was operated for the full sampling day, with measurements taken approximately every minute, and stored in a data-logger. The instruments were calibrated with a “zero” gas, and a 100-ppm calibration gas, automatically diluted (in Thermo Environmental Instruments Multigas Calibration System, Model 146) to a value in the anticipated range of measurement.

CEM for O_3:

A Thermo Environmental Instruments Model 49 CEM was used to monitor O_3, also in a range of 0-100ppb. The inlet tube to the Model 49 was positioned inside the exhaust duct, in order to obtain maximum values along with less random, wind-caused variability. It was operated for the full sampling day, with measurements taken approximately every minute, and stored in the same data-logger that was used for NO_x measurements. The Model 49 will be calibrated with an internal ozone generator in the anticipated range of measurement.

CEM for CO:

An Advanced Pollution Instrumentation Model 300A CO Analyzer was used to monitor carbon monoxide in the range of 0-100ppm. The inlet tube to the Model 300A was positioned inside the exhaust duct, in order to obtain maximum values along with less random, wind-caused variability. It was operated for the full sampling day, with measurements taken approximately every minute, and stored in the same data-logger used for the NO_x and O_3 measurements. The instrument was calibrated with a “zero” gas, and an appropriate calibration gas, automatically diluted (in Thermo Environmental Instruments Multigas Calibration System, Model 146) to a value in the anticipated range of measurement.

Ultraviolet Radiation:

UV radiation was measured using an International Light IL1400A Radiometer/Photometer. The UV sensor was positioned in the vicinity of the welder. It was operated for the full sampling day, with measurements taken approximately every minute, and stored in the same data-logger that was used for $NO_{x,}$ O_3, and CO measurements.

Appendix C
Data Quality Assurance/Quality Control Plan

NFESC personnel, not connected with the project, conducted an internal review of the test results and interpretations, as did the environmental contractor, VERSAR, Inc. Results from each test event were reviewed to evaluate the integrity of the demonstration. Written and properly signed records of each periodic review show the date of the review, the demonstration inspected, the person performing the review, any findings and problems, actions recommended and taken to resolve existing problems, and any scheduled date for reevaluation.

The Quality Assurance Officer designated for this ESTCP project is Mr. Robert (Bob) Weber, Corps of Engineers Research Laboratory (CERL). By the time the project was completed, Mr. Weber had retires and there was no replacement identified. Therefore, the project team depended on the environmental contractor to conduct the review. The Navy Consolidated Industrial Hygiene Laboratory, San Diego, CA is accredited by the American Industrial Hygiene Association and conducts quality control on all samples.

Environmental Protection Samples

Emission testing will be completed using a nine-stage cascade impactor for collecting particulate samples in accordance with a modified EPA Methods 1-5 [C-1]. Continuous emission monitors (CEMs) will be used to measure real-time NO_x, O_3, and CO emission concentrations.

Quality assurance measures for the particulate sampling included:

- Performing one sampling run on filtered ambient air through the impactor to help estimate impactor filter media weight change as well as clean air metal concentrations.
- Desiccating every filter media before and after use to eliminate humidity-related influences on media weight.
- Performing analysis of filter media blanks at least weekly to determine blank metal concentrations.
- Calibrate balances used to weigh filter media daily with known certified weight. Check and adjust (if necessary) balance zero for each weighing.
- Forward all filter media to lab using strict chain-of-custody procedures/forms.

Quality assurance measures for CEMs included:

- Daily calibration of NO_x and CO CEMs using “zero” air and certified concentration gases for spanning.

[C-1] EPA Code of Federal Regulations (CFR) Promulgated Test Methods, 1- Traverse Points, 2- Velocity, 3- Molecular Weight, 4- Moisture Content, and 5- Particulate Material, http://www.epa.gov/ttn/emc/promgate.html *(accessed 2/4/2010)*

- Daily calibration of O_3 CEM using “zero” gas and internal spanning methodology.
- Calibration as needed during each run when data were suspect.

Occupational Safety and Health Samples

The Naval Environmental Health Center's *Field Operations Manual* http://www-nehc.med.navy.mil/Occupational_Health/Industrial_Hygiene/ih_fieldops_manual.aspx (accessed 2/4/2010) and the *Industrial Hygiene Sampling Guide for Consolidated Industrial Hygiene Laboratories (CIHLs)* http://www-nehc.med.navy.mil/downloads/IH/CIHL%20GUIDE%202009Rev1.pdf (accessed 2/4/2010) are used as the quality control, quality assurance basis for the testing.

Area sampling for hexavalent chromium will be performed in accordance with OSHA Method ID-215 recommendations. The following collection protocol will be followed for worker exposure testing.

- Daily calibration of the personal sampling pumps to approximately 2 L/min flow rate with a cassette in line.
- After sampling, placed plastic end caps tightly on both ends of the cassettes.
- Forward cassettes to analytical laboratory under strict chain-of-custody procedures and forms.
- Samples were stored on ice at the end of each sampling day, during shipment, and during storage until refrigeration is possible at the laboratory.

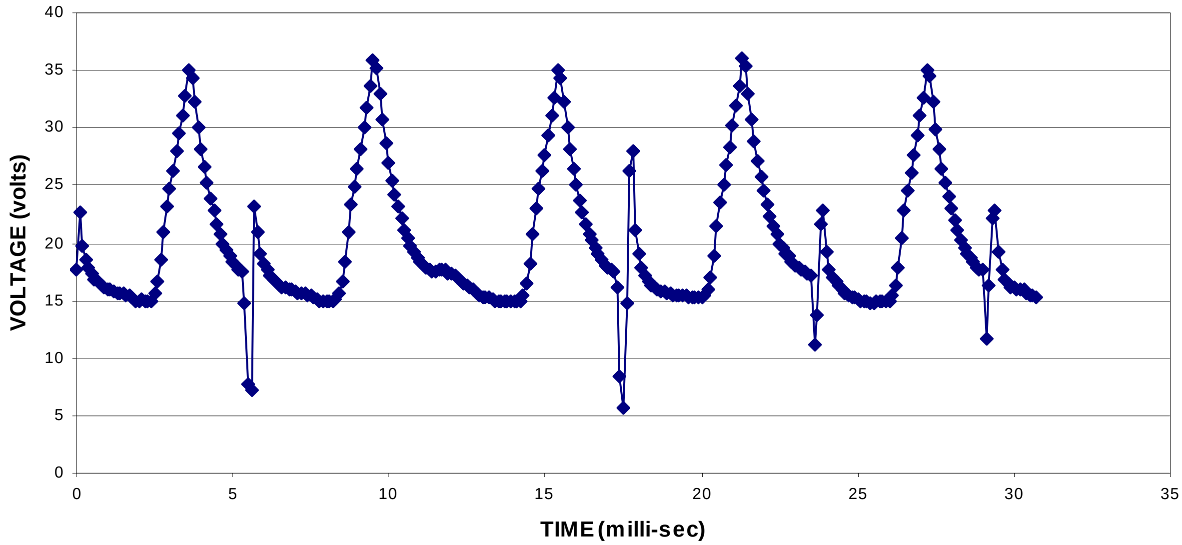
Other Sample Handling Procedures

Sample traceability was maintained on all samples using standard chain-of-custody forms, daily logs, and other documentation as appropriate. Traceability, defined as the ability to reconstruct reported test results back to the original sampling and analysis data and how it was generated, includes the following:

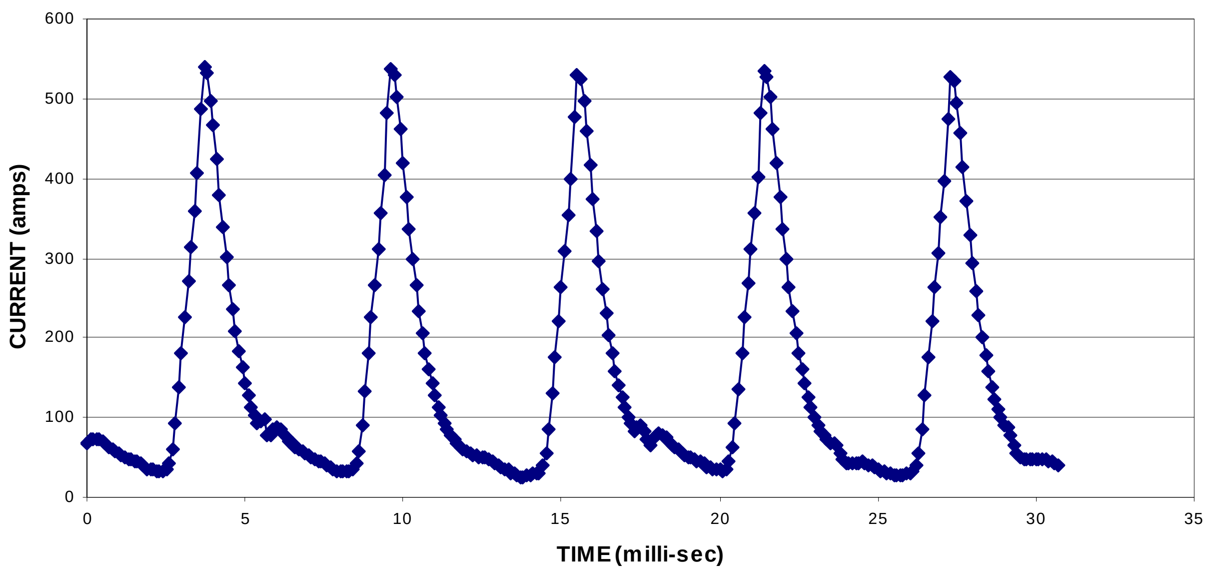
- Identification and calibration of measurements and test equipment used to collect or analyze samples.
- Use of a project logs or equivalently identified data collection forms.
- Source, purity, and preparation of standard reference materials used in quantitative or qualitative analysis.
- Incorporation by reference or full description of methodologies and technically necessary modifications performed.
- Sequence (i.e., time, date, and order) that samples were processed or analyzed**.**

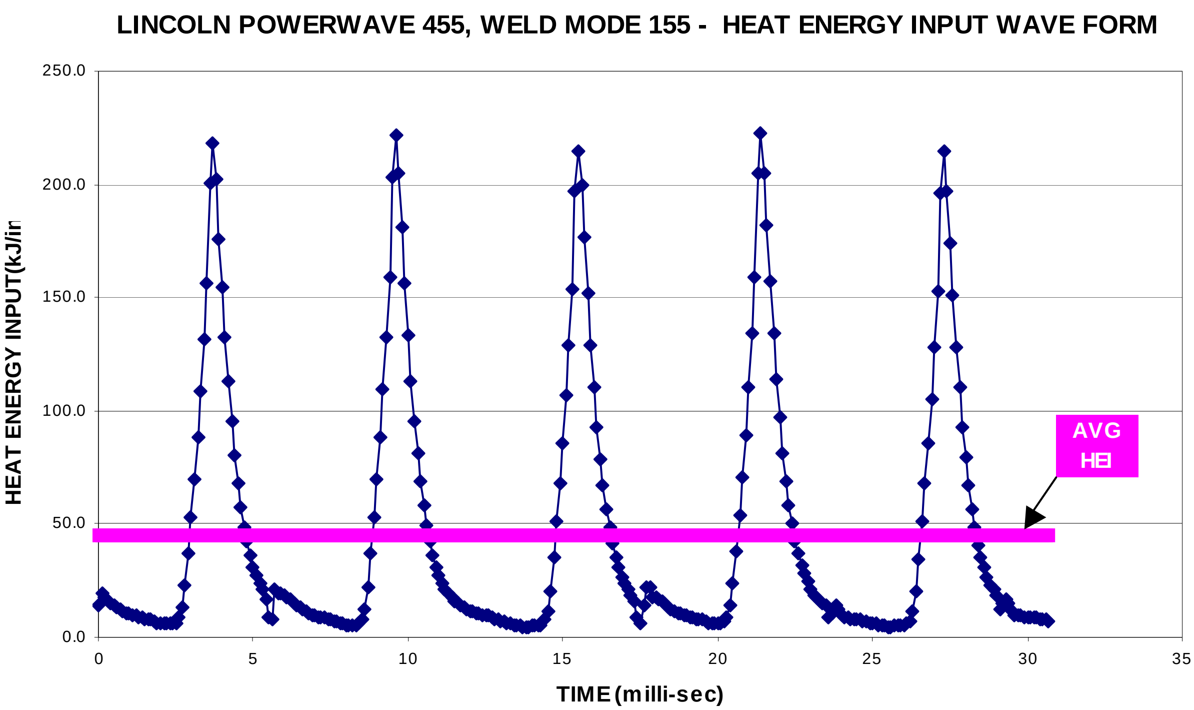
Appendix D
Example Wave Forms from Machine Tested at PSNSY

LINCOLN POWERWAVE 455, WELD MODE 155 - VOLTAGE WAVE FORM



LINCOLN POWERWAVE 455, WELD MODE 155 - CURRENT WAVE FORM




LINCOLN POWERWAVE 455, WELD MODE 155 - HEAT ENERGY INPUT WAVE FORM
HEAT ENERGY INPUT(kJ/in
TIME (milli-sec)
AVG
HEI
0.0
50.0
100.0
150.0
200.0
250.0
0
5
10
15
20
25
30
35

Appendix E
Example Continuous Emissions Data

Fig. E-1. CONTINUOUS EMISSION DATA (<u>Without</u> Pulsed Power Inverter)
28 Sep 04, SWRMC, San Diego, CA
(Stick Welding - not wire)

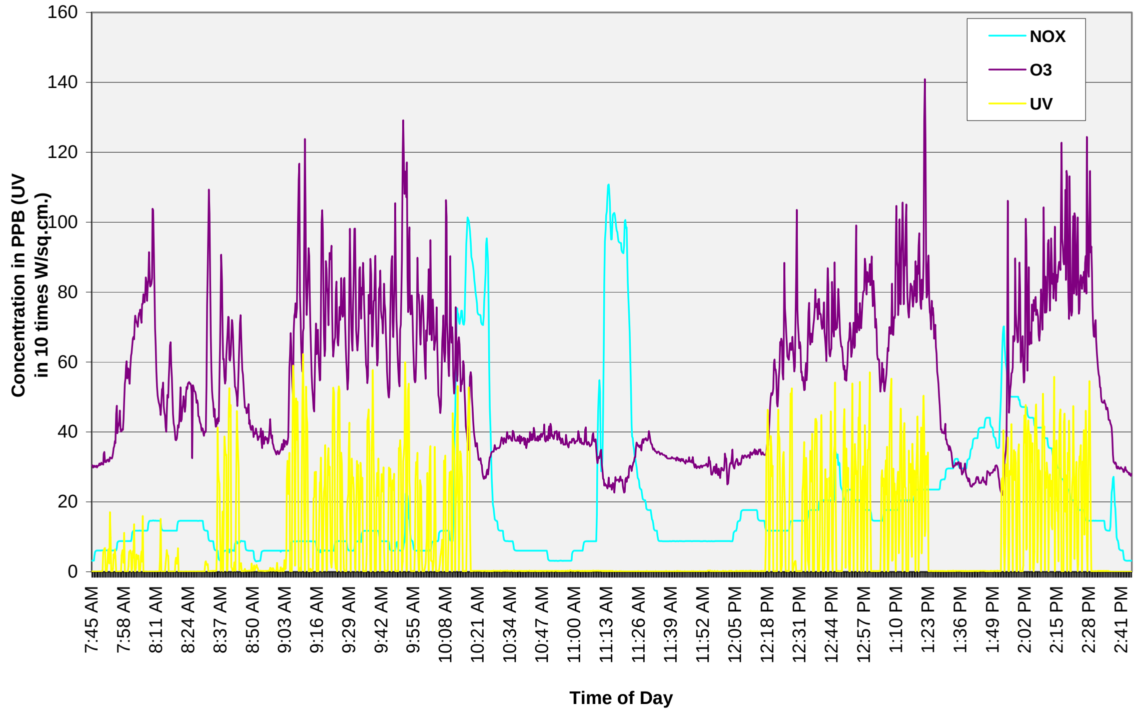
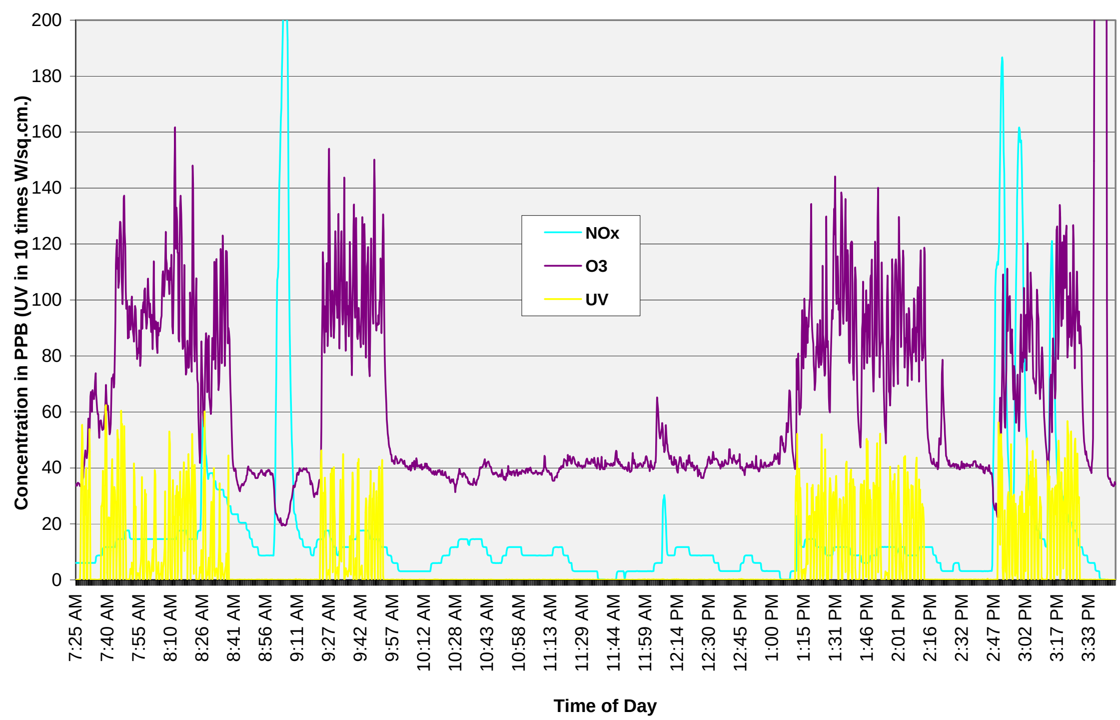


Fig. E-2. CONTINUOUS EMISSION DATA (<u>Without</u> Pulsed Power Inverter)
29 Sep 04, SWRMC, San Diego, CA
(Stick Welding - not wire)



Note: UV values for SWRMA, San Diego are shown at 10 times their actual value to accommodate graphic representation. Therefore, a value shown as of 40 watts/cm^2 is actually 4 watts/cm^2.

Fig. E-3. CONTINUOUS EMISSION DATA (With Pulsed Power Inverter)
30 Sep 04, SWRMC, San Diego, CA

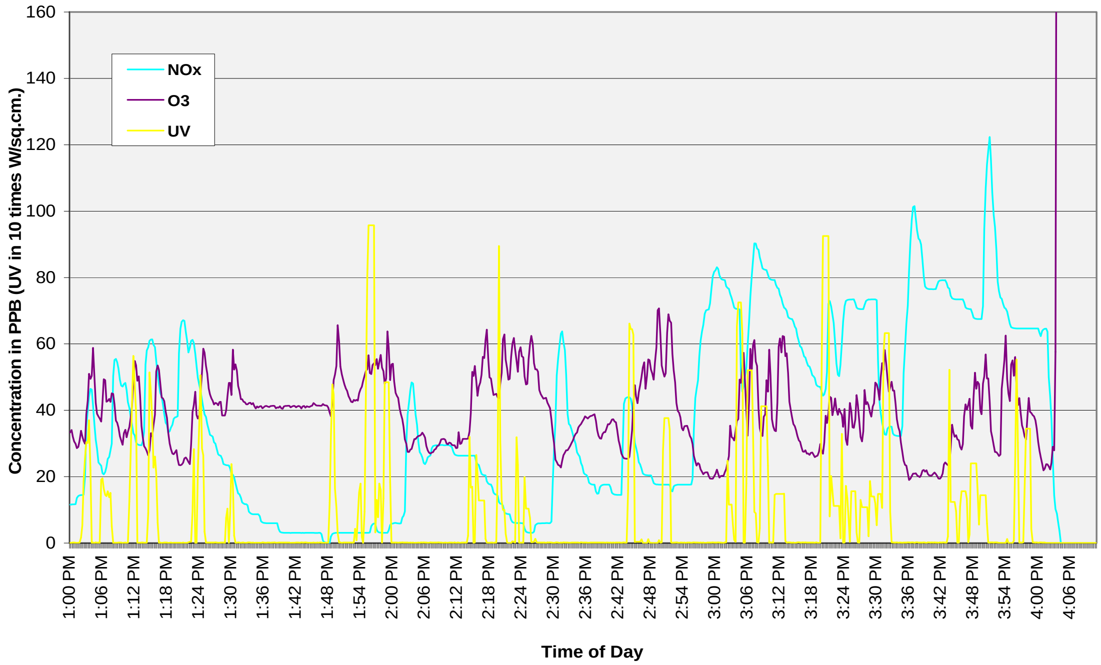
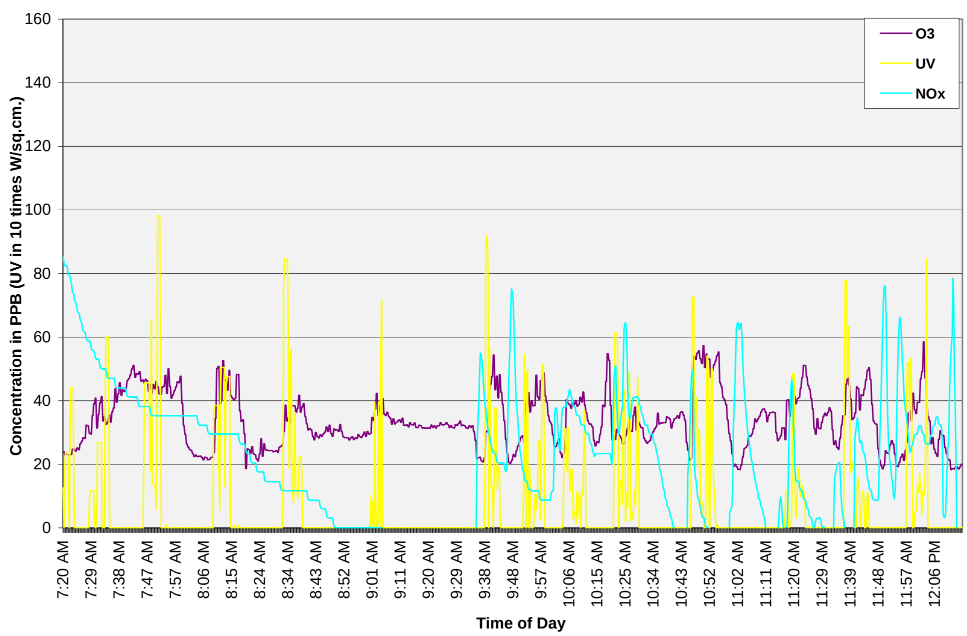


Fig. E-4. CONTINUOUS EMISSIONS DATA (With Pulsed Power Inverter)
1 Oct 04, SWRMC, San Diego, CA



Note: UV values for SWRMA, San Diego are shown at 10 times their actual value to accommodate graphic representation. Therefore, a value shown as of 40 watts/cm^2 is actually 4 watts/cm^2.

Fig. E-5. CONTINUOUS EMISSION DATA (With Pulsed Power Inverter)
4 Oct 04, SWRMC, San Diego, CA

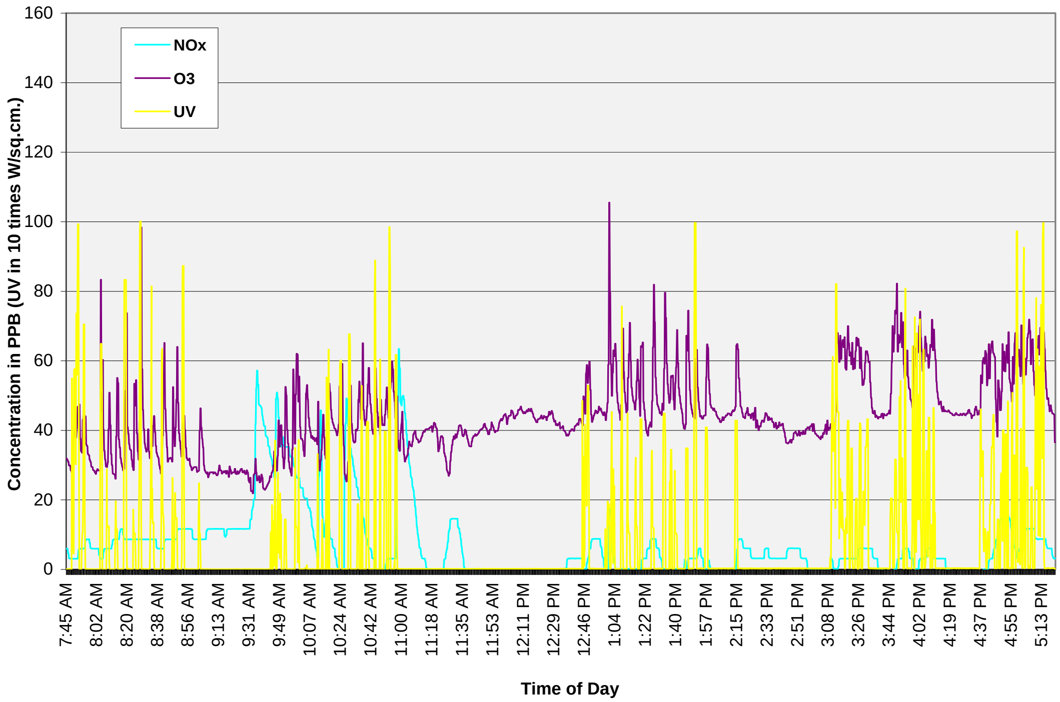
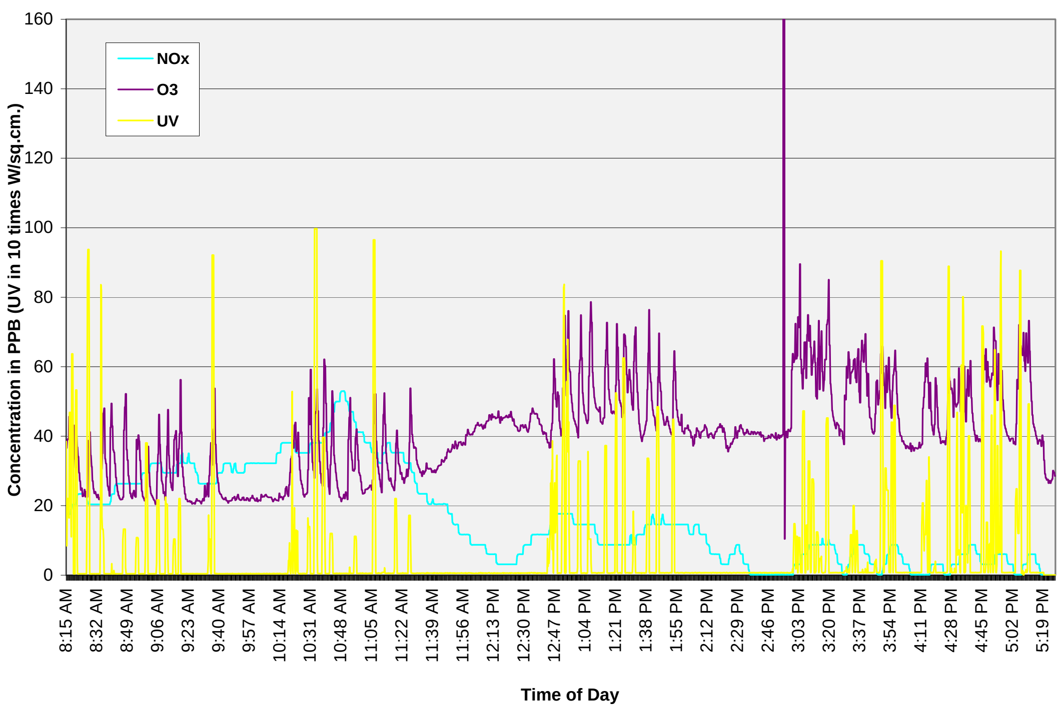


Fig. E-6. CONTINUOUS EMISSION DATA (With Pulsed Power Inverter)
5 Oct 04, SWRMC, San Diego, CA



Note: UV values for SWRMA, San Diego are shown at 10 times their actual value to accommodate graphic representation. Therefore, a value shown as of 40 watts/cm^2 is actually 4 watts/cm^2.

Fig. E-7. CONTINUOUS EMISSION DATA (Without Pulsed Power Inverter)
6 Oct 04, SWRMC, San Diego, CA
(Stick - not wire)

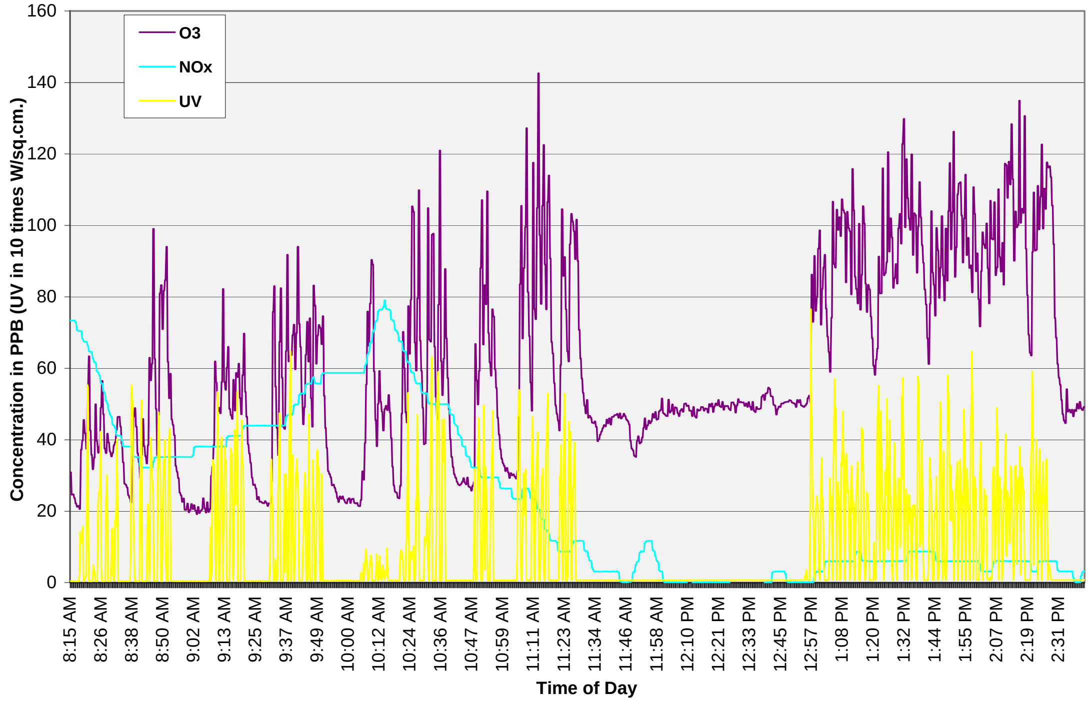
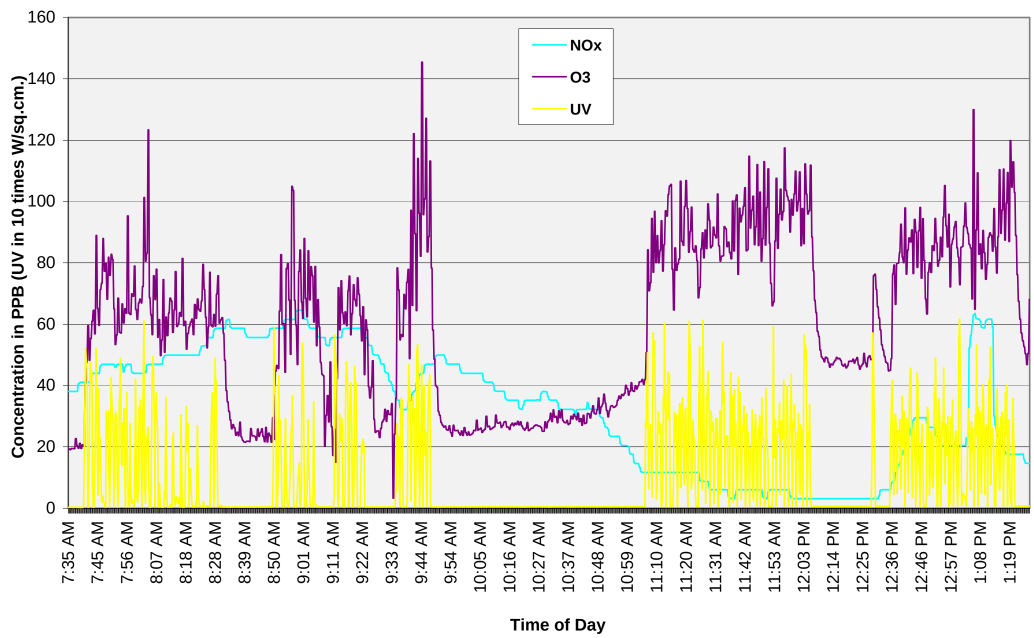


Fig. E-8. CONTINUOUS EMISSION DATA (Without Pulsed Power Inverter)
7 Oct 04, SWRMC, San Diego, CA
(Stick Welding - not wire)



Note: UV values for SWRMA, San Diego are shown at 10 times their actual value to accommodate graphic representation. Therefore, a value shown as of 40 watts/cm^2 is actually 4 watts/cm^2.

Fig. E-9. CONTINUOUS EMISSION DATA (<u>with</u> Pulsed Power Inverter)
11Aug 04 - PSNS, Bremerton, WA

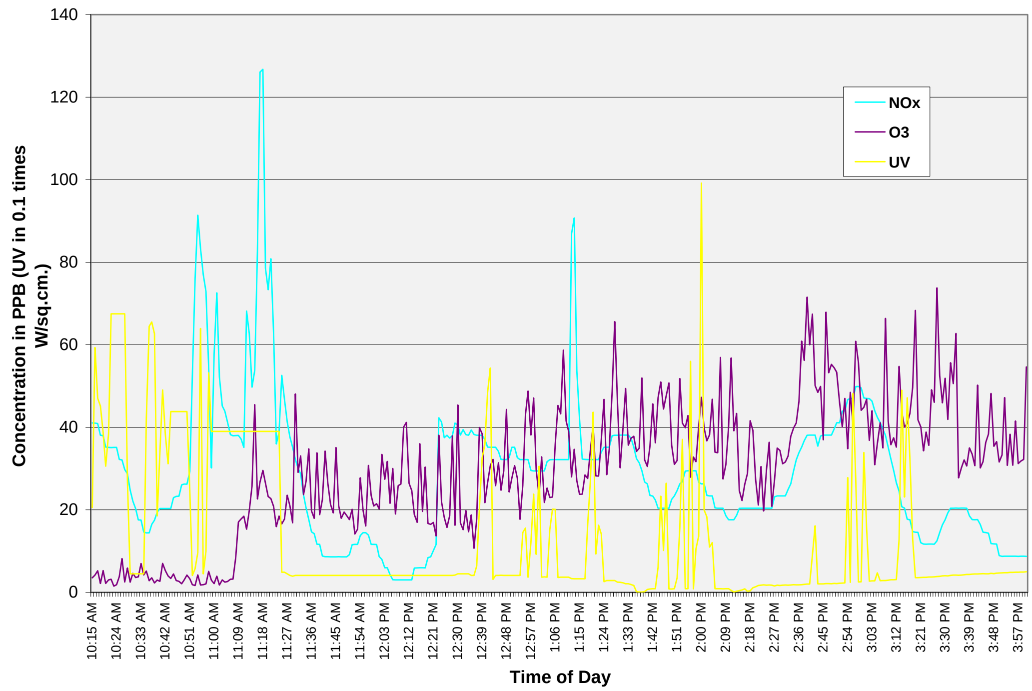
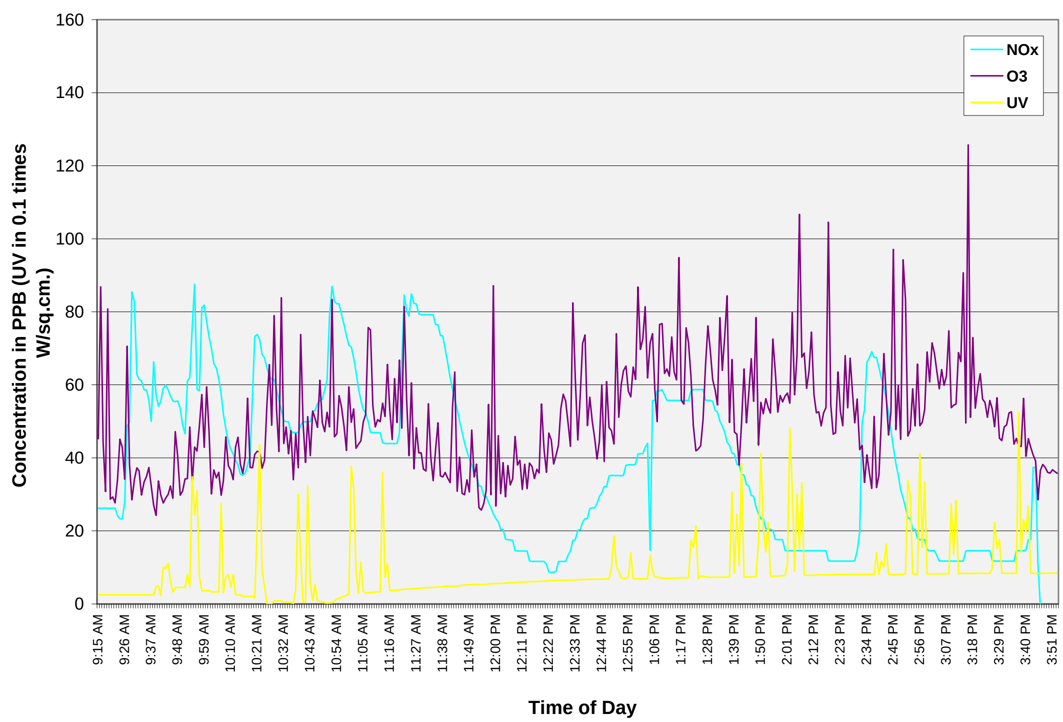


Fig. E-10. CONTINUOUS EMISSION DATA (<u>Without</u> Pulsed Power Inverter)
12 Aug 04 - PSNS, Bremerton, WA
(Stick Welding - not wire)



Note: UV values for PSNSY, Bremerton, WA are shown at 0.1 times their actual value to accommodate graphic representation. Therefore, a value shown as of 40 watts/cm^2 is actually 400 watts/cm^2.

Fig. E-11. CONTINUOUS EMISSIONS DATA (<u>with</u> Pulsed Power Inverter)
13 Aug 04 -PSNS, Bremerton, WA

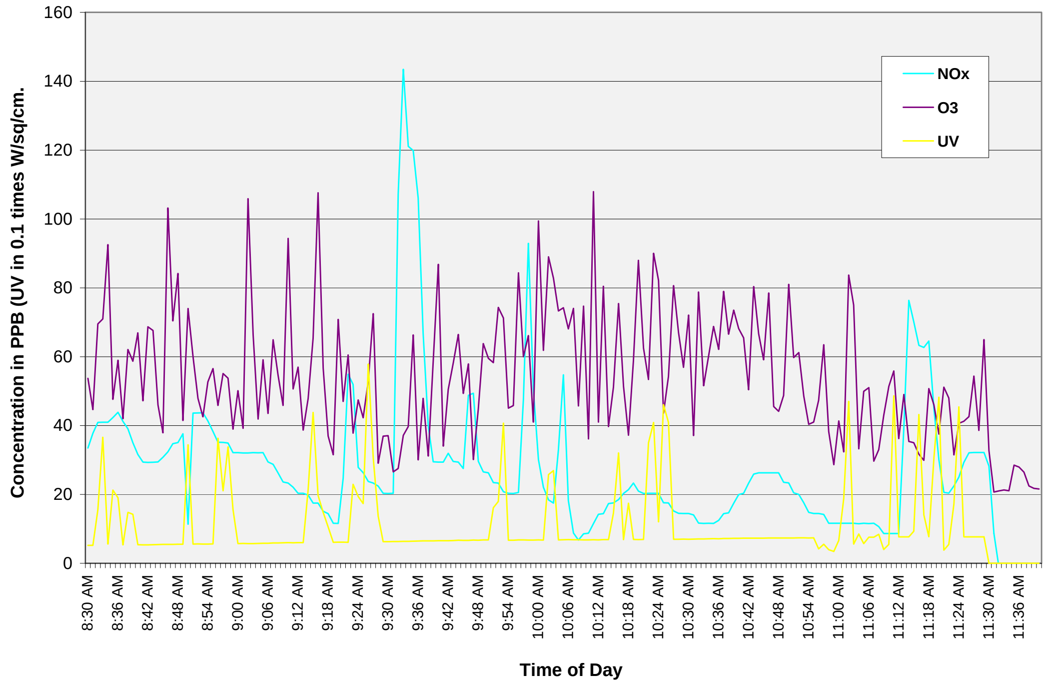
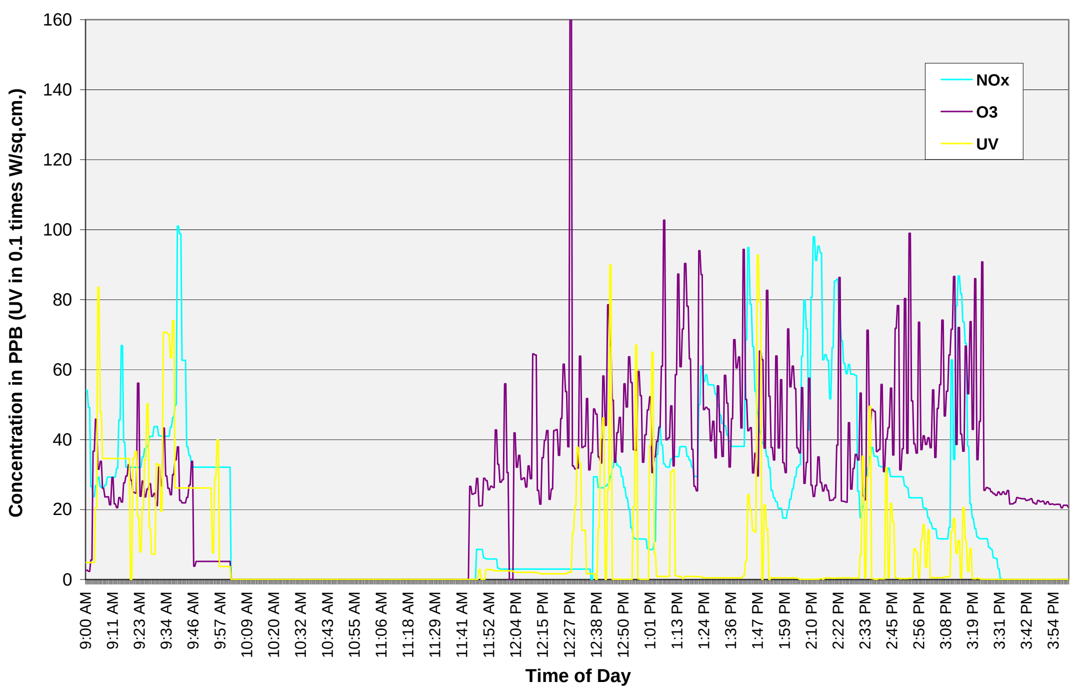


Fig. E-12. CONTINUOUS EMISSION DATA (<u>with</u> Pulsed Power Inverter)
16 Aug 04 - PSNS, Bremerton, WA



Note: UV values for PSNSY, Bremerton, WA are shown at 0.1 times their actual value to accommodate graphic representation. Therefore, a value shown as of 40 watts/cm^2 is actually 400 watts/cm^2.

Fig. E-13. CONTINUOUS EMISSION DATA (with Pulsed Power Inverter)
17 Aug 04 - PSNS - Bremerton, WA

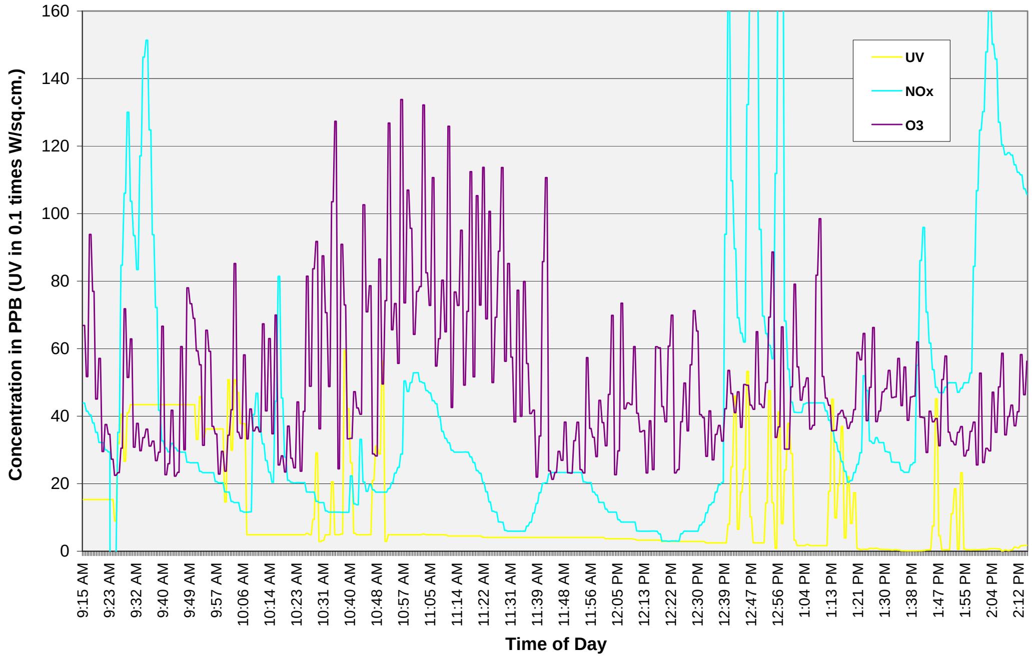
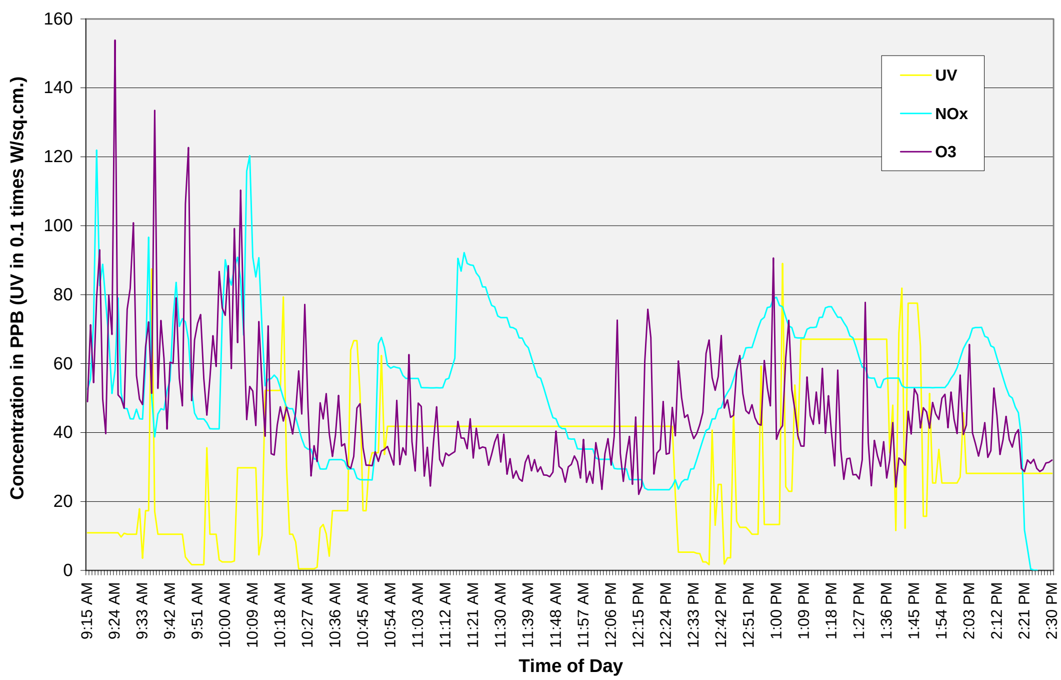
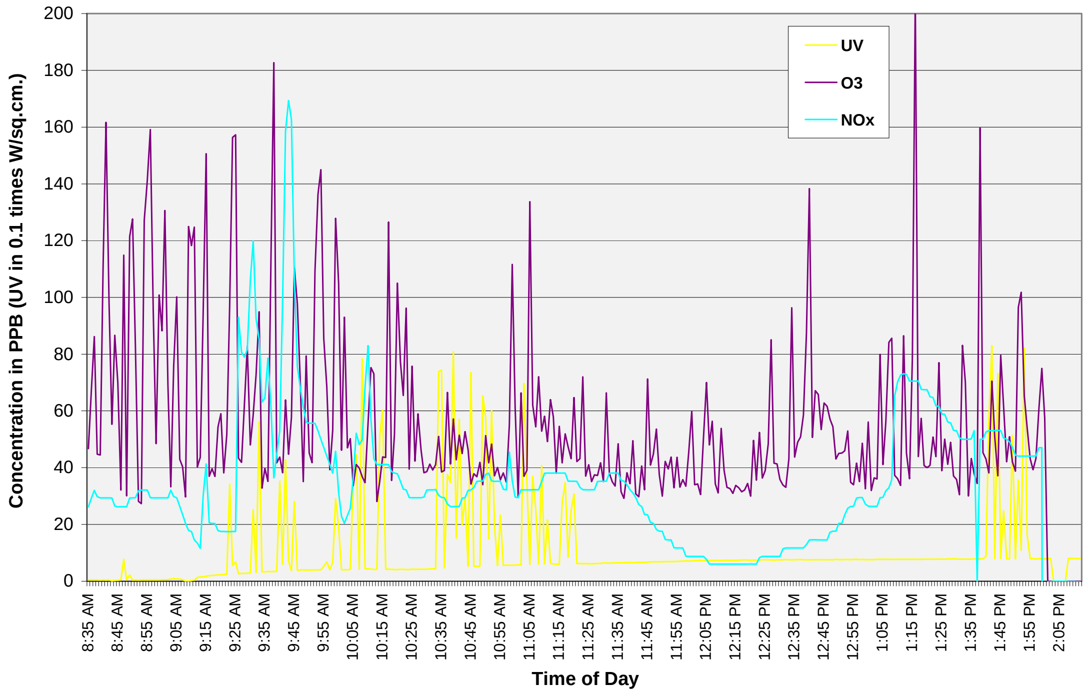


Fig. E-14. CONTINUOUS EMISSION DATA (with Pulsed Power Inverter)
18 Aug 04 - PSNS - Bremerton, WA



Note: UV values for PSNSY, Bremerton, WA are shown at 0.1 times their actual value to accommodate graphic representation. Therefore, a value shown as of 40 watts/cm^2 is actually 400 watts/cm^2.

Fig. E-15. CONTINUOUS EMISSION DATA (<u>with</u> Pulsed Power Inverter)
19 Aug 04 - PSNS - Bremerton, WA



Note: UV values for PSNSY, Bremerton, WA are shown at 0.1 times their actual value to accommodate graphic representation. Therefore, a value shown as of 40 watts/cm^2 is actually 400 watts/cm^2.

Fig. E-16. CONTINUOUS EMISSION DATA (<u>Without</u> Pulsed Power Inverter) - 10/22/03 - Anniston Army Depot

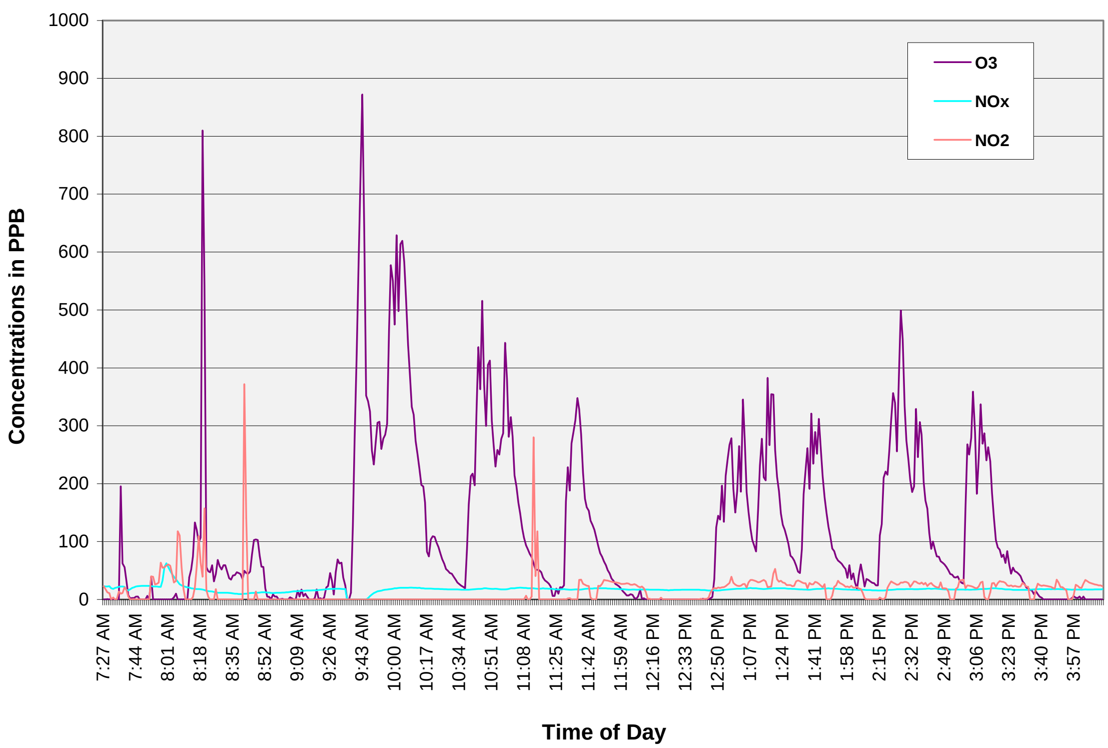


Fig. E-17. CONTINUOUS EMISSION DATA (<u>Without</u> Pulsed Power Inverter) - 10/23/03 - Anniston Army Depot

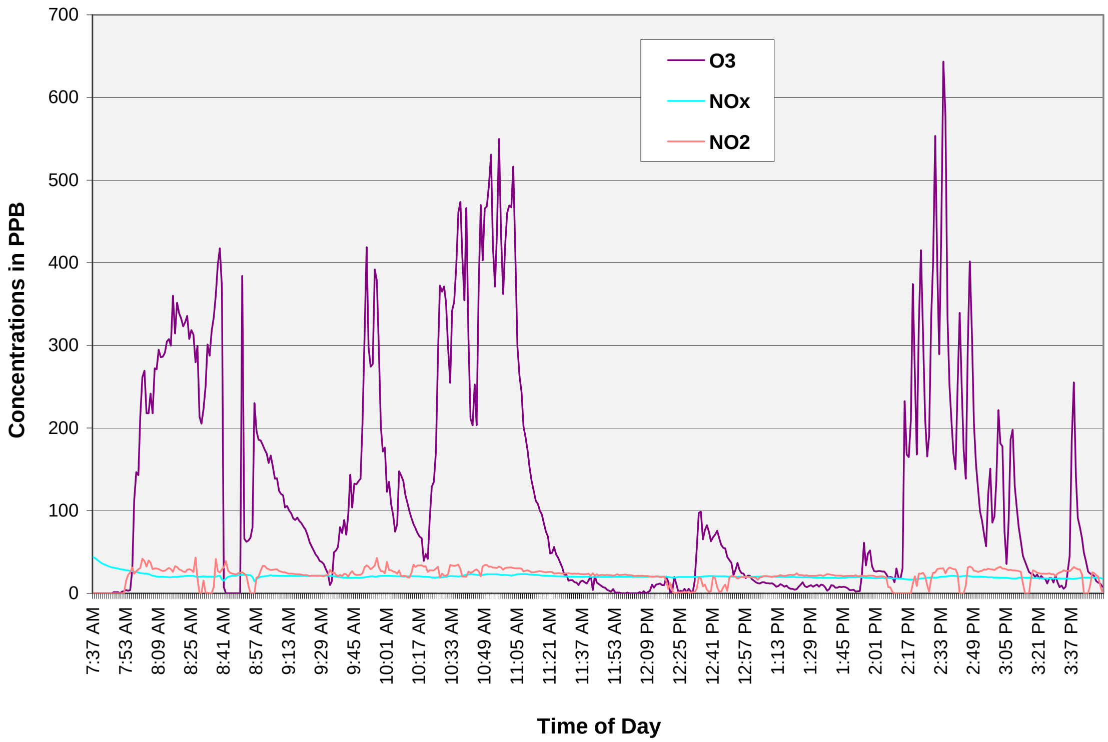


Fig. E-18. CONTINUOUS EMISSION DATA (<u>Without</u> Pulsed Power Inverter) - 10/24/03 - Anniston Army Depot

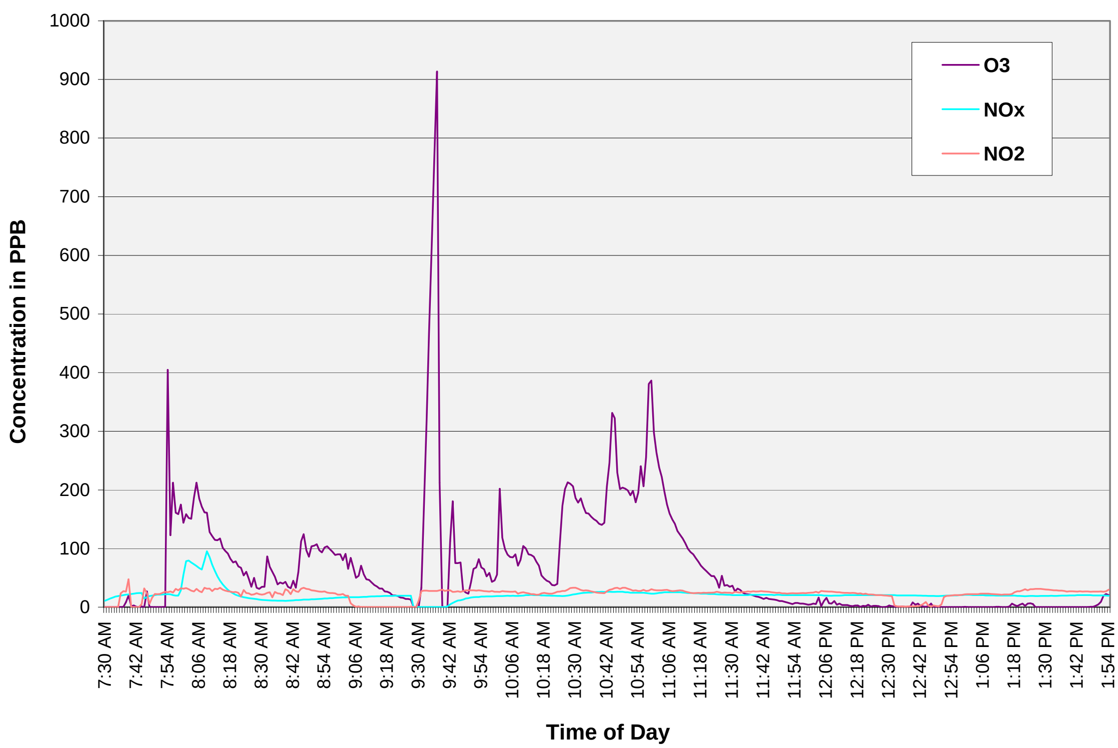


Fig. E-19. CONTINUOUS EMISSION DATA 10/27/03 - Anniston Army Depot

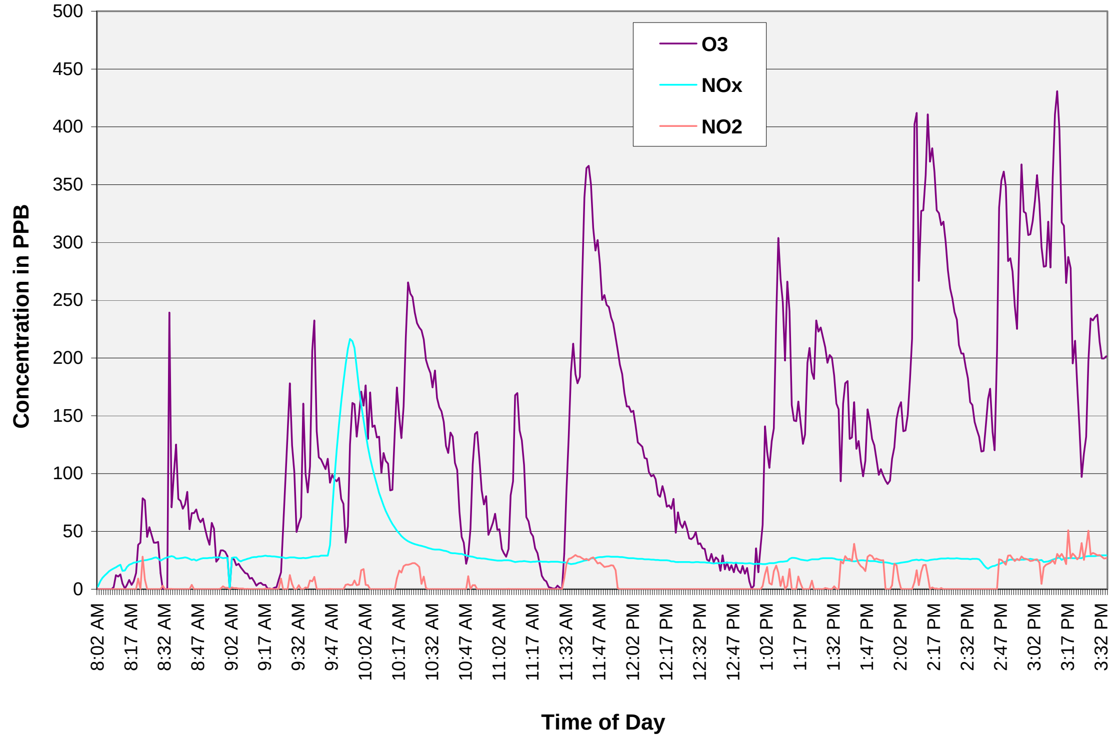


Fig. E-20. CONTINUOUS EMISSION DATA (<u>With</u> Pulsed Power Inverter) - 10/28/03 - Anniston Army Depot

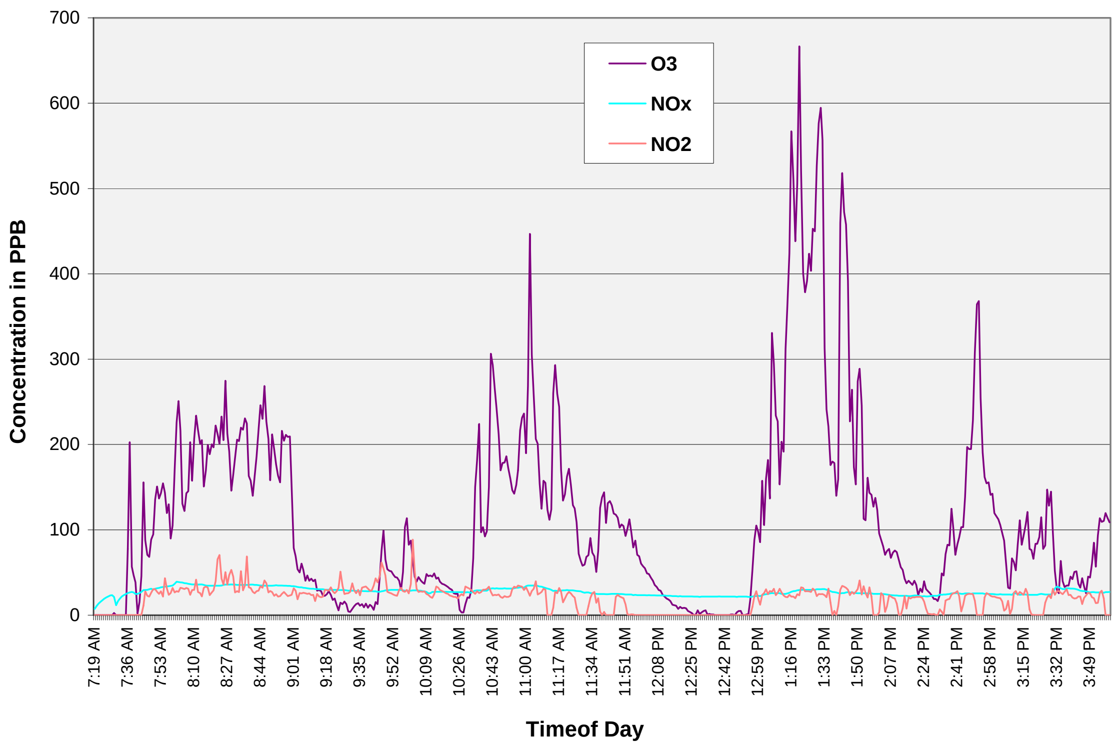


Fig. E-21. CONTINUOUS EMISSION DATA (With Pulsed Power Inverter) - 10/29/03 - Anniston Army Depot

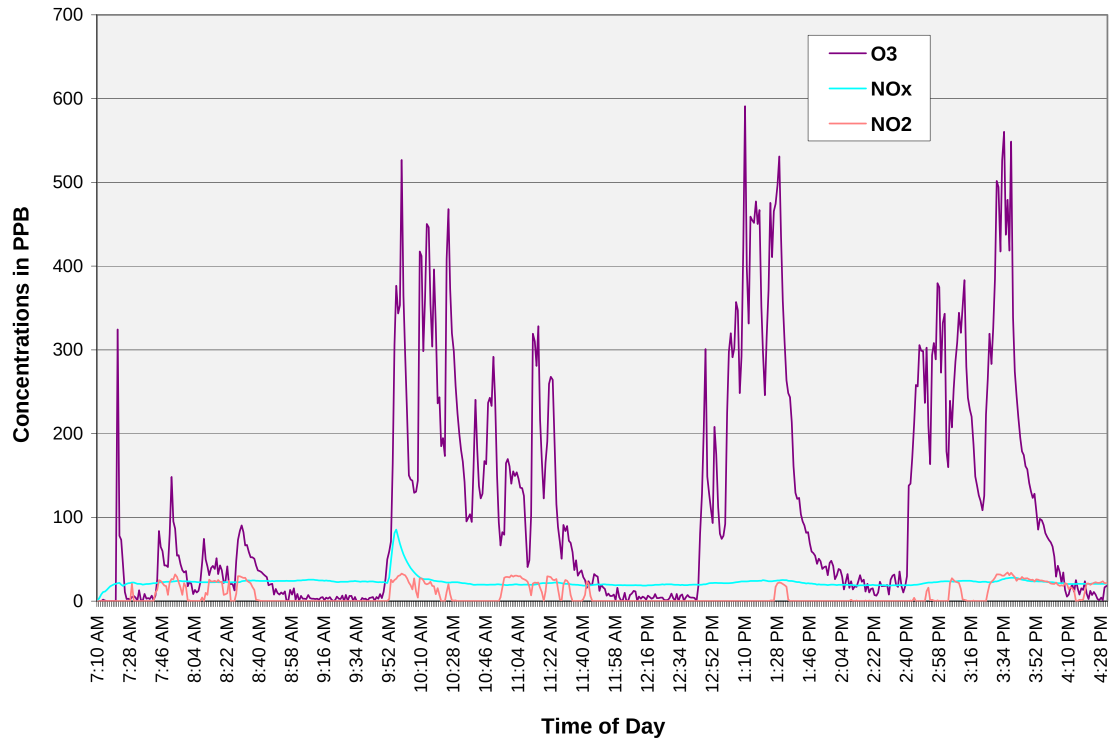


Fig. E-22. CONTINUOUS EMISSION DATA - 10/30/03 - Anniston Army Depot (ALUMINUM Welding)

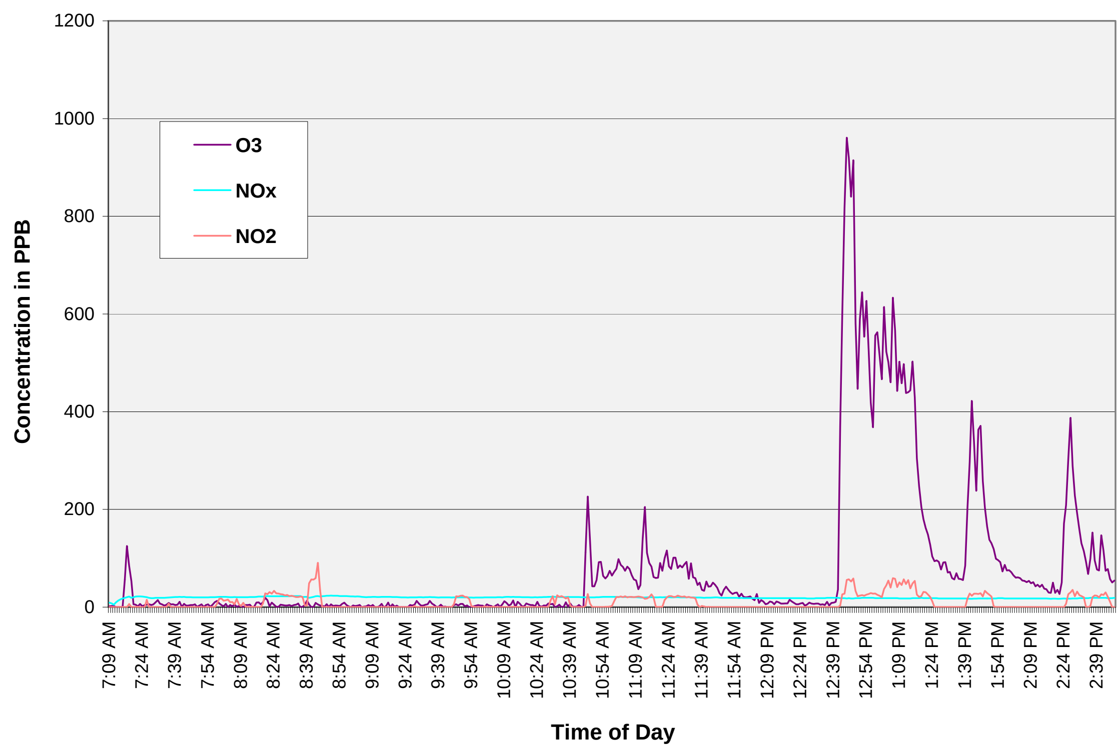


Fig. E-23. CONTINUOUS EMISSIONS DATA - 11/18/03 - MCLB, Albany, GA

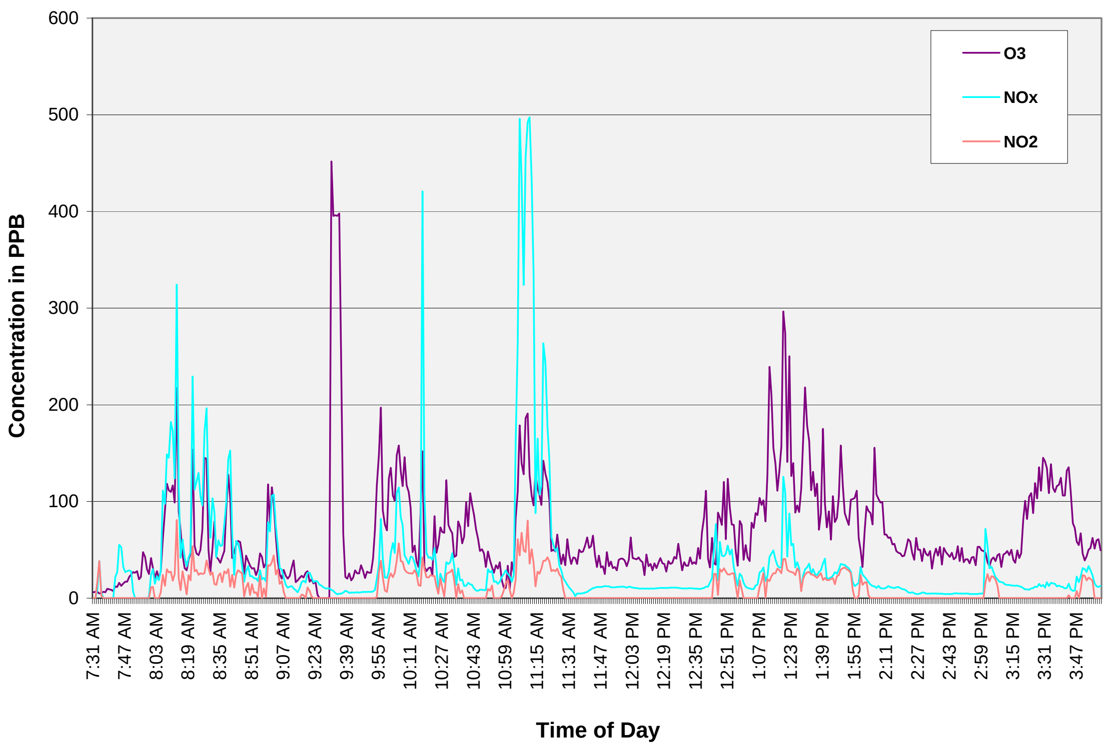


Fig. E-24. CONTINUOUS EMISSION DATA - 11/19/03 - MCLB, Albany, GA

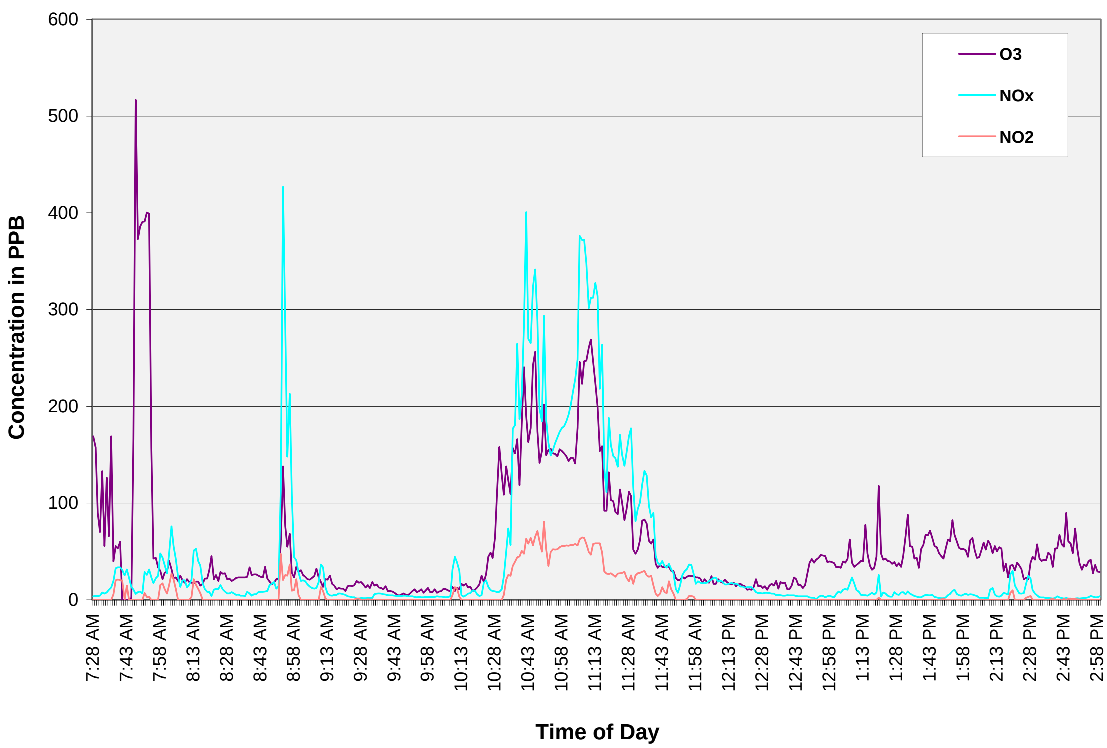


Fig. E-25. CONTINUOUS EMISSION DATA - 11/20/03 - MCLB, Albany, GA

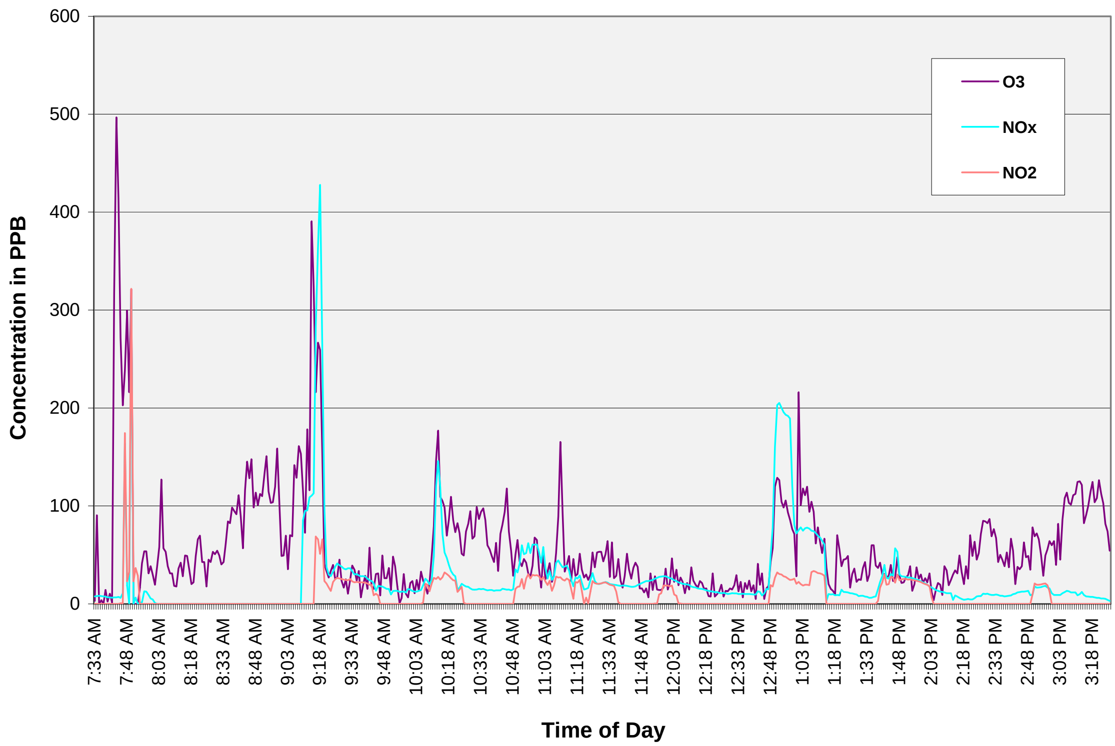
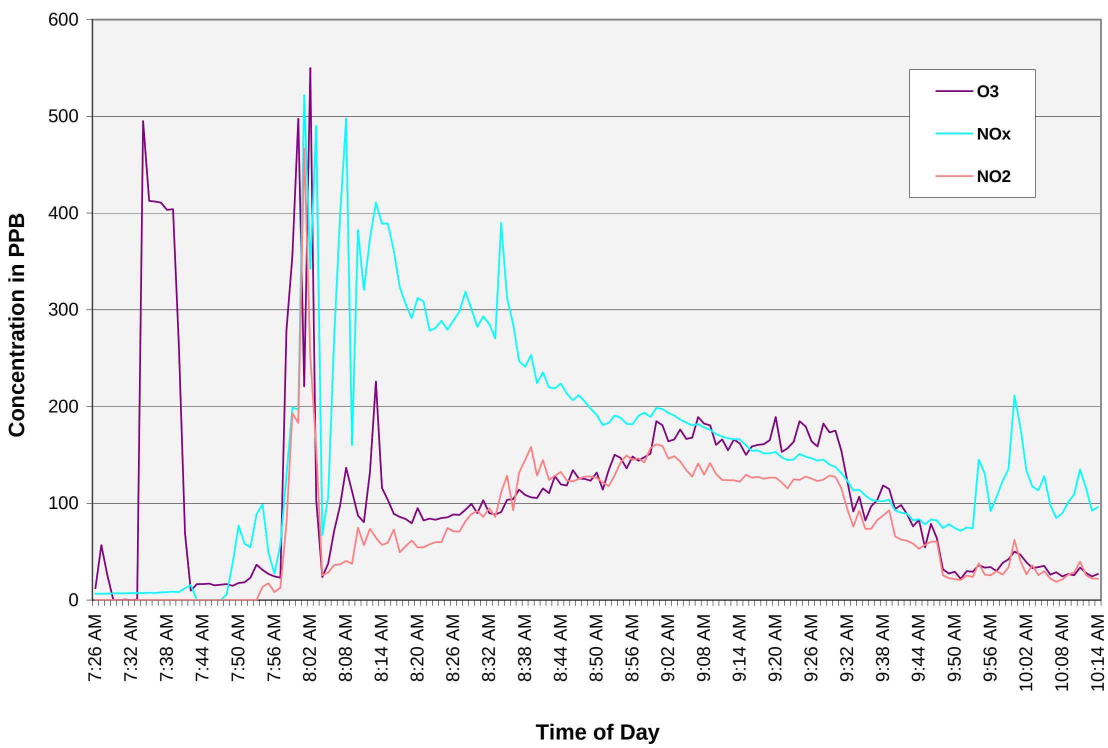


Fig. E-26. CONTINUOUS EMISSION DATA - 11/21/03 - MCLB, Albany, GA



Appendix F
Environmental Emission Rates and Pie Charts

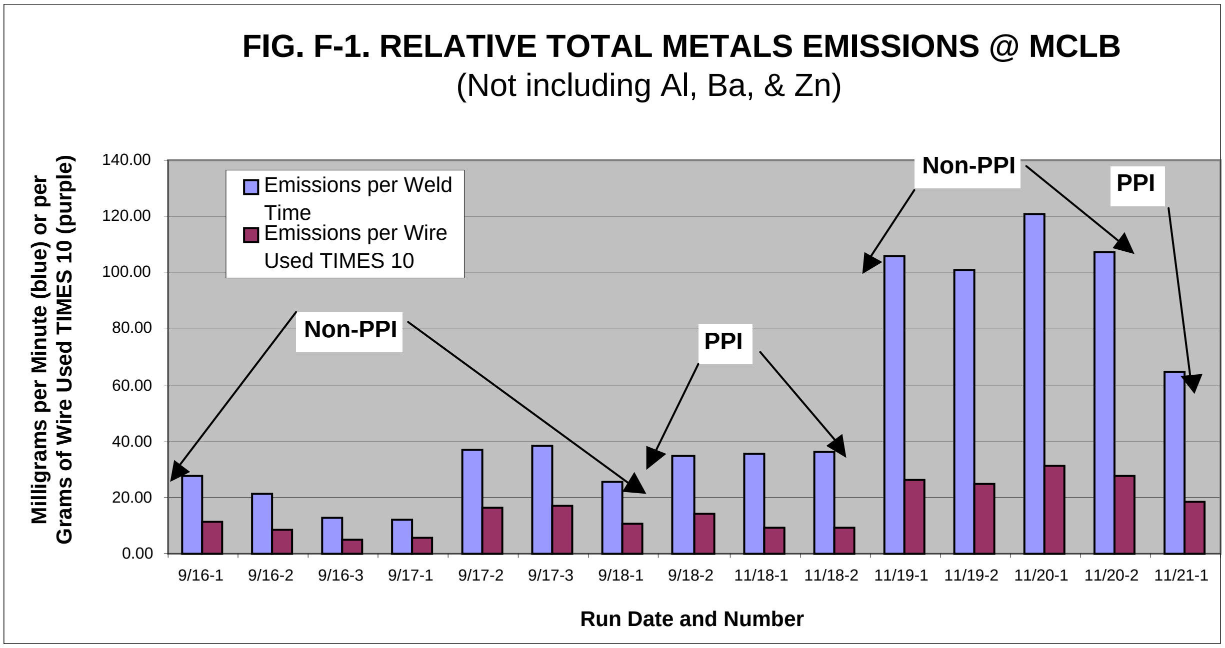


FIG. F-1. RELATIVE TOTAL METALS EMISSIONS @ MCLB
(Not including Al, Ba, & Zn)
Milligrams per Minute (blue) or per Grams of Wire Used TIMES 10 (purple)
Emissions per Weld Time
Emissions per Wire Used TIMES 10
Non-PPI
PPI
Non-PPI
PPI
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
9/16-1
9/16-2
9/16-3
9/17-1
9/17-2
9/17-3
9/18-1
9/18-2
11/18-1
11/18-2
11/19-1
11/19-2
11/20-1
11/20-2
11/21-1
Run Date and Number

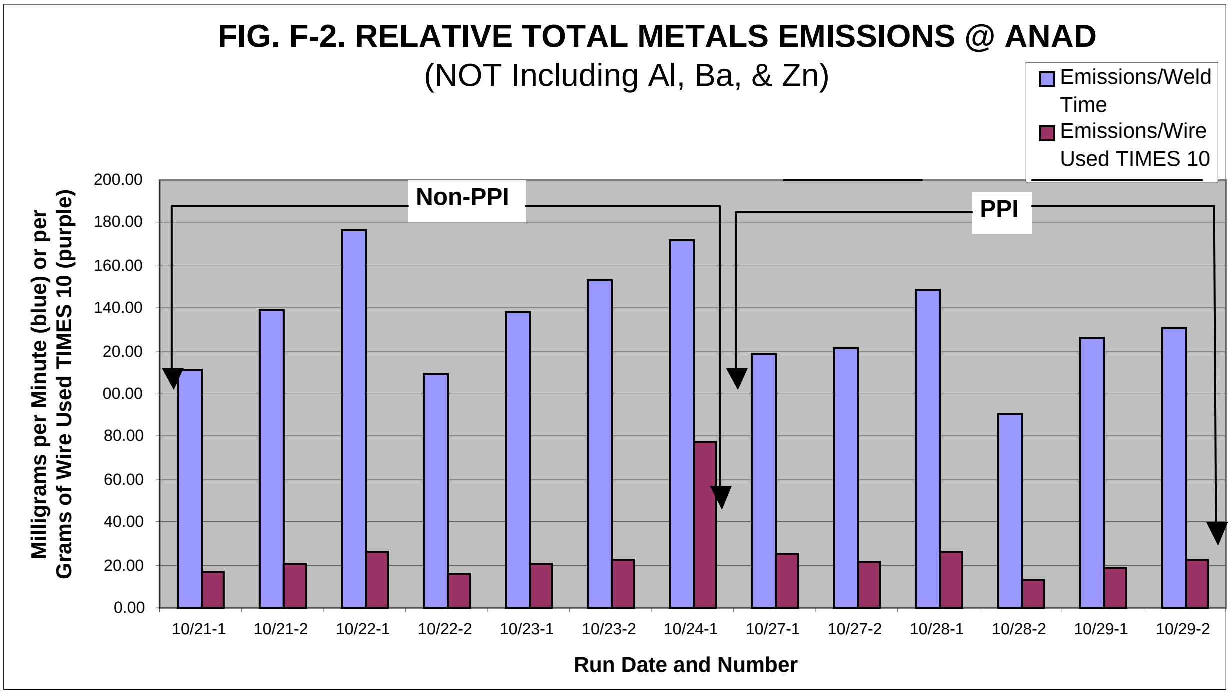


FIG. F-2. RELATIVE TOTAL METALS EMISSIONS @ ANAD
(NOT Including Al, Ba, & Zn)
Emissions/Weld Time
Emissions/Wire Used TIMES 10
Milligrams per Minute (blue) or per Grams of Wire Used TIMES 10 (purple)
Non-PPI
PPI
200.00
180.00
160.00
140.00
20.00
00.00
80.00
60.00
40.00
20.00
0.00
10/21-1
10/21-2
10/22-1
10/22-2
10/23-1
10/23-2
10/24-1
10/27-1
10/27-2
10/28-1
10/28-2
10/29-1
10/29-2
Run Date and Number

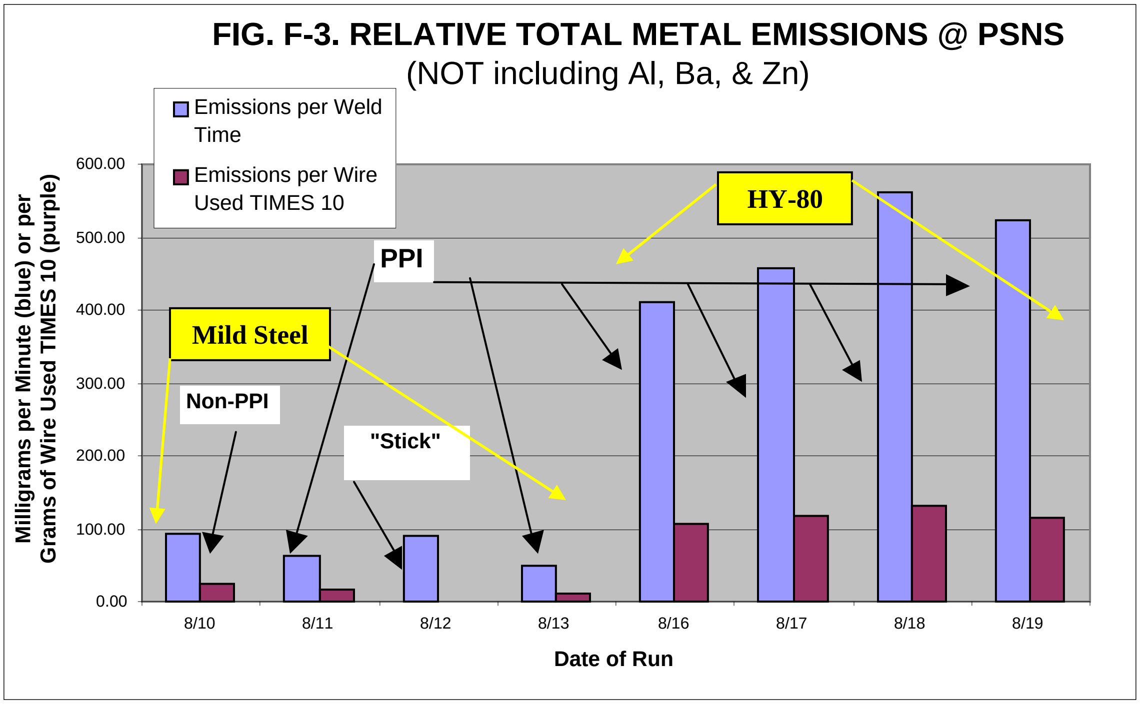


FIG. F-3. RELATIVE TOTAL METAL EMISSIONS @ PSNS
(NOT including Al, Ba, & Zn)
Emissions per Weld Time
Emissions per Wire Used TIMES 10
Milligrams per Minute (blue) or per Grams of Wire Used TIMES 10 (purple)
600.00
500.00
400.00
300.00
200.00
100.00
0.00
HY-80
PPI
Mild Steel
Non-PPI
"Stick"
8/10
8/11
8/12
8/13
8/16
8/17
8/18
8/19
Date of Run

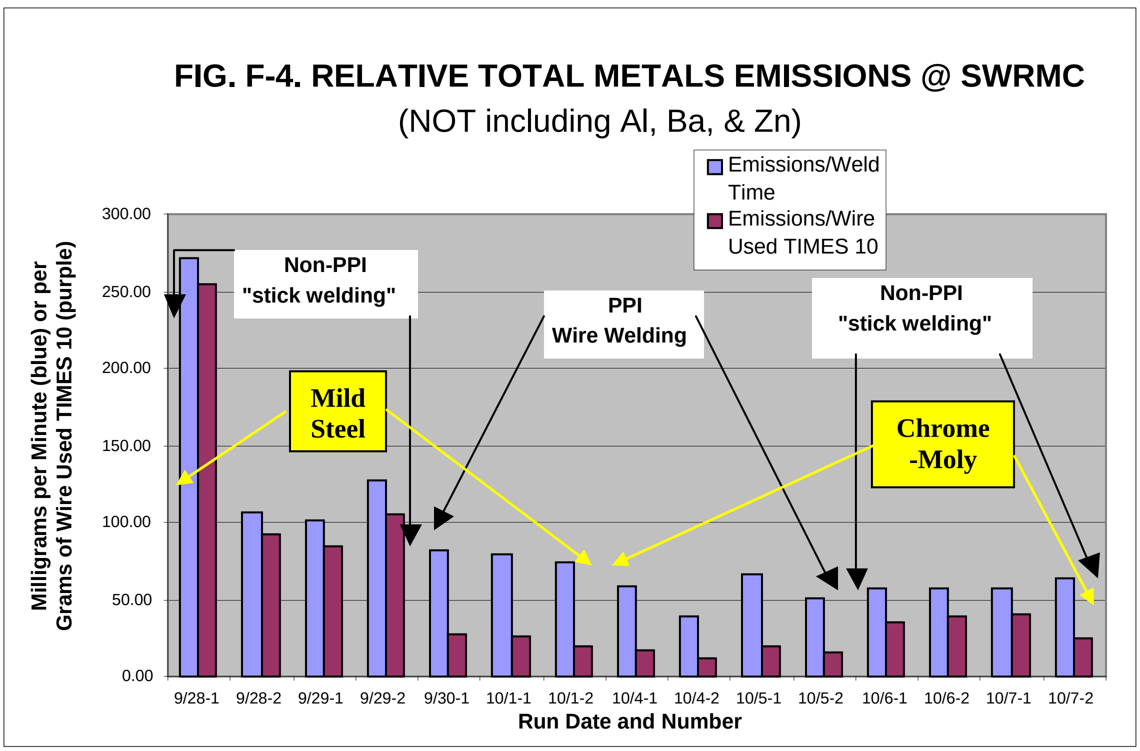


FIG. F-4. RELATIVE TOTAL METALS EMISSIONS @ SWRMC
(NOT including Al, Ba, & Zn)
Emissions/Weld Time
Emissions/Wire Used TIMES 10
Milligrams per Minute (blue) or per Grams of Wire Used TIMES 10 (purple)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Non-PPI "stick welding"
PPI Wire Welding
Non-PPI "stick welding"
Mild Steel
Chrome -Moly
9/28-1
9/28-2
9/29-1
9/29-2
9/30-1
10/1-1
10/1-2
10/4-1
10/4-2
10/5-1
10/5-2
10/6-1
10/6-2
10/7-1
10/7-2
Run Date and Number

Table F-1: Marine Corps Logistics Base Impactor Weight Gains

WEIGHT GAINS FOR IMPACTOR STAGES @ MCLB, Albany, GA, Adjusted for blank weight loss (mg)

Sample No. (date)	Cascade Impactor Stage Number									Tot. Adjust. Wt. (mg)	Welding Time (min)	Wt of Sample/Time (mg/min)	Wt of solids @ full flow/Time (mg/min)	Total wire used/run (gm)	Total emissions/Wire used (mg/gm)
	1	2	3	4	5	6	7	8	9 (Filter)						
1(9/16/03)	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.44	n/a	n/a	n/a	271	2.34
2(9/16/03)	0.00	0.70	0.38	0.40	0.20	0.20	0.02	0.05	0.00	1.95	29.50	0.07	95	734	3.84
3(9/16/03)	0.46	0.80	0.45	0.61	0.39	0.26	0.37	0.33	0.25	3.94	n/a	n/a	n/a	1,057	5.38
4(9/17/03)	0.28	0.47	0.39	0.00	0.48	0.70	0.40	0.17	0.34	3.23	34.55	0.09	135	770	6.06
5(9/17/03)	0.00	0.87	0.39	0.36	0.27	0.48	0.62	0.27	1.50	4.76	40.06	0.12	171	893	7.70
6(9/17/03)	0.06	0.50	0.26	0.74	0.16	0.30	0.07	0.20	1.11	3.42	42.08	0.08	117	938	5.27
7(9/18/03)	0.90	0.00	0.24	0.16	0.62	0.00	0.05	0.00	0.02	1.99	45.28	0.04	63	1,121	2.56
8(9/18/03)	0.06	0.23	0.25	0.18	0.23	0.30	0.52	0.37	1.22	3.36	46.53	0.07	104	1,152	4.21
9(11/18/03)	0.00	0.05	0.05	0.00	0.22	0.00	0.06	0.00	0.10	0.48	59.62	0.01	12	2,379	0.29
10(11/18/03)	0.26	0.03	0.30	0.09	0.21	0.00	0.34	0.11	1.53	2.87	61.18	0.05	68	2,442	1.70
11(11/19/03)	0.05	0.12	0.41	0.04	0.36	0.23	0.60	0.08	2.26	4.15	30.22	0.14	198	1,231	4.87
12(11/19/03)	0.31	0.00	0.53	0.26	0.56	0.55	1.15	1.46	3.77	8.59	60.38	0.14	205	2,459	5.04
13(11/20/03)	0.13	0.26	0.42	0.26	0.50	0.41	1.12	0.45	4.78	8.33	60.43	0.14	199	2,325	5.17
14(11/20/03)	0.52	0.27	0.25	0.39	0.41	0.72	0.88	1.04	4.30	8.78	60.17	0.15	211	2,315	5.48
15(11/21/03)	0.24	0.09	0.15	0.22	0.23	0.53	0.73	0.86	2.83	5.88	64.22	0.09	132	2,234	3.80
Averages	**0.2**	**0.1**	**0.3**	**0.2**	**0.4**	**0.3**	**0.7**	**0.6**	**2.8**			**0.091**	**132**		**4.25**
% of Tot. Weight	**3.9**	**2.1**	**5.4**	**3.2**	**6.4**	**6.2**	**12.5**	**10.2**	**50.1**	**Standard Deviation:**		**0.044**	**63**		**1.89**

NOTE 1: All values in stages 1-8 have been adjusted for blank weight loss of 0.34 mg (i.e., values shown are 0.34 mg higher than actual weight gains.

NOTE 2: All adjusted values that were negative have been changed to zero.

NOTE 3: Shaded samples did not have impactor stages properly assembled. Therefore, individual stage values are not correct. Only total sample weights are correct.

NOTE 4: Averages, % of total weights, and standard deviation do not include shaded areas (see Note 3) except for totals.

NOTE 5: Runs 9, 10, and 15 are pulsed power inverter welding. Runs 11-14 are conventional pulsed power.

NOTE 6: The column headed "Weight of solids @ full flow/Time" is calculated by multiplying the column headed "Weight of sample/Time" by the ratio of the flow in the ventilation duct to the flow in the sample train (1,444).

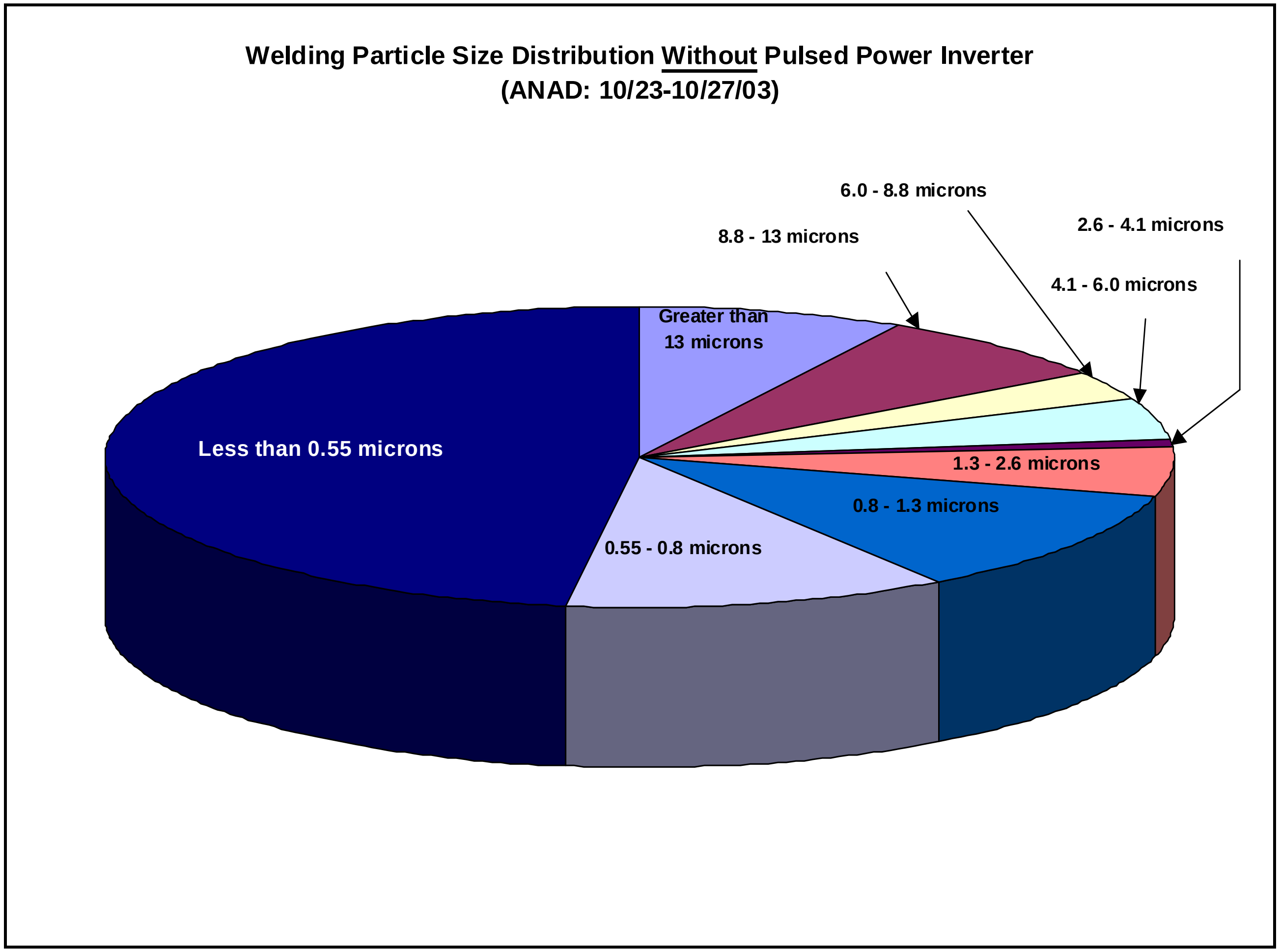


FIGURE F-5: Welding Particle Size Distribution- ANAD

Table F-2: Anniston Army Depot Impactor Weight Gain

WEIGHT GAINS FOR IMPACTOR STAGES @ Anniston Army Depot, Adjusted for blank weight loss (mg)

Sample No. (date)	Cascade Impactor Stage Number 1	2	3	4	5	6	7	8	9 (Filter)	Tot. Adjust. Wt. (mg)	Welding Time (min)	Wt/Time (mg/min)	Wt of solids @ full flow/Time (mg/min)	Total wire used/run (gm)	Total emissions/Wire used (mg/gm)
1(10/21/03)	2.6	0.8	2.1	0.2	0.2	2.1	0.0	0.3	0.6	9.2	35.12	0.26	377	2,362	5.61
2(10/21/03)	10.1	0.4	1.0	0.7	0.7	0.5	0.4	0.3	0.3	14.7	45.75	0.32	465	3,078	6.91
3(10/22/03)	4.4	1.1	2.5	0.3	0.0	0.1	1.3	0.0	0.9	10.9	30.07	0.36	524	2,023	7.79
4(10/22/03)	0.0	0.3	1.3	0.5	1.5	1.0	0.8	1.2	2.4	9.3	42.13	0.22	318	2,834	4.73
5(10/23/03)	0.0	0.9	0.4	1.9	0.1	1.3	0.9	0.0	2.0	7.8	39.35	0.20	285	2,647	4.24
6(10/23/03)	0.2	0.2	0.1	0.0	0.0	0.2	0.0	0.9	2.2	4.0	16.08	0.25	363	1,082	5.39
7(10/24/03)	0.4	0.0	0.2	0.3	0.0	0.0	0.8	0.0	2.2	4.1	15.52	0.26	382	346	17.11
8(10/27/03)	0.3	0.7	0.0	0.2	0.0	0.4	0.6	0.5	1.7	4.6	21.72	0.21	309	1,029	6.51
9(10/27/03)	0.0	0.5	0.1	0.3	0.4	0.5	0.9	1.5	4.7	9.2	41.52	0.22	321	2,376	5.60
10(10/28/03)	0.2	0.2	0.2	0.6	0.3	0.9	0.6	1.6	4.9	9.8	36.25	0.27	391	2,075	6.83
11(10/28/03)	0.3	0.0	0.1	0.3	0.0	0.1	0.0	0.1	1.7	2.8	22.87	0.12	179	1,535	2.67
12(10/29/03)	0.0	0.2	0.2	0.0	0.2	0.3	0.0	1.4	4.2	6.7	39.52	0.17	245	2,652	3.65
13(10/29/03)	0.3	0.1	0.0	0.0	0.0	0.1	0.4	0.5	1.7	3.4	21.28	0.16	229	1,235	3.95
14(10/30/03)	0.0	0.0	0.0	0.0	0.3	0.2	0.7	1.5	4.5	7.4	19.98	0.37	538	227	47.33
Averages	**0.2**	**0.3**	**0.1**	**0.2**	**0.1**	**0.3**	**0.4**	**0.8**	**2.9**			**0.23**	**338**		**6.23**
% of Tot. Weight	**4.4**	**4.8**	**2.6**	**4.2**	**2.5**	**6.2**	**7.9**	**15.2**	**52.1**	**Standard Deviation:**		**0.066**	**95**		**3.58**

NOTE 1: All values in stages 1-8 have been adjusted for blank weight loss of 0.34 mg (i.e., values shown are 0.34 mg higher than actual weight gains.

NOTE 2: All adjusted values that were negative have been changed to zero.

NOTE 3: Sample No. 14 is for welding on Aluminum. All other samples are for steel alloys.

NOTE 4: Shaded samples did not have impactor stages properly assembled. Therefore, individual stage values are not correct. Only total sample weights are correct.

NOTE 5: Averages, % of total weights, and standard deviation do not include shaded areas (see Note 4) except for totals, and do not include run AAD 14 (see Note 3).

NOTE 6: Runs 9-13 are pulsed power inverter welding. Runs 1-8 are conventional pulsed power.

NOTE 7: The column headed "Weight of solids @ full flow/Time" is calculated by multiplying the column headed "Weight of sample/Time" by the ratio of the flow in the ventilation duct to the flow in the sample train (1,444).

Table F-3: Puget Sound Naval Shipyard Impactor Weight Gain

WEIGHT GAINS FOR IMPACTOR STAGES @ PSNS, Bremerton, WA, Adjusted for blank weight loss (mg)

Sample No. (date)	**Cascade Impactor Stage Number**									**Tot. Adjust. Wt. (mg)**	**Welding Time (min)**	**Wt/Time (mg/min)**	**Wt of solids @ full flow/Time (mg/min)**	**Total wire used/run (gm)**	**Total emissions/Wire used (mg/gm)**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9 (Filter)**						
1(8/10/04)	0.44	0.14	0.14	0.24	0.44	0.34	0.34	1.14	5.20	8.42	40.00	0.21	317	1,482	8.56
2(8/11/04)	0.24	0.34	0.34	0.34	0.54	0.54	0.64	0.64	2.00	5.62	46.05	0.12	184	1,885	4.49
3(8/12/04)	0.24	0.24	0.44	0.64	0.54	1.34	2.74	2.54	2.90	11.62	60.83	0.19	288	rod, not wire	n/a
4(8/13/04)	0.24	0.34	0.34	0.34	0.34	0.24	0.74	0.84	1.60	5.02	40.52	0.12	187	1,658	4.56
5(8/16/04)	0.04	0.04	0.24	0.34	0.34	0.44	0.54	0.54	1.20	3.72	53.80	0.07	104	2,070	2.71
6(8/17/04)	0.24	0.24	0.24	0.24	0.24	0.34	0.34	0.34	1.00	3.22	44.98	0.07	108	1,731	2.80
7(8/18/04)	0.24	0.04	0.34	0.24	0.14	0.24	0.24	0.34	1.20	3.02	40.03	0.08	114	1,696	2.68
8(8/19/04)	0.44	0.54	0.44	0.44	0.74	0.74	0.74	1.54	6.10	11.72	48.02	0.24	368	2,211	7.98
Averages	**0.3**	**0.2**	**0.3**	**0.4**	**0.4**	**0.5**	**0.8**	**1.0**	**2.7**	**6.5**		**0.138**	**209**		**4.83**
% of Tot. Weight	**4.0**	**3.7**	**4.8**	**5.4**	**6.3**	**8.1**	**12.1**	**15.1**	**40.5**	**Standard Deviation:**		**0.068**	**103**		**2.49**

NOTE 1: All values in stages 1-8 have been adjusted for blank weight loss of 0.34 mg (i.e., values shown are 0.34 mg higher than actual weight gains.

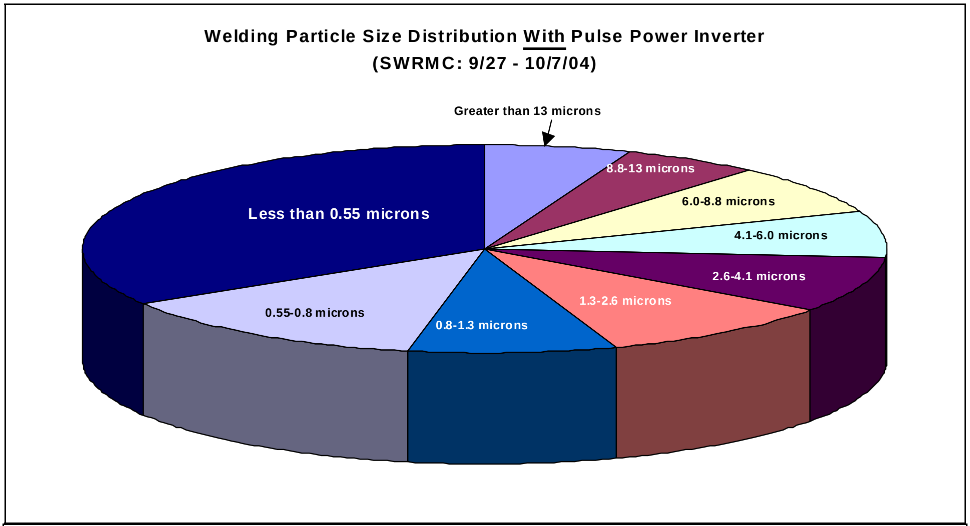
NOTE 2: All adjusted values that were negative have been changed to zero.

NOTE 3: All runs are wire-type welding, except run 3 (shaded row), which is "stick" welding.

NOTE 4: Runs 1 and 3 are conventional pulsed power. Runs 2 and 4-8 are with pulsed power inverter.

NOTE 5: The column headed "Weight of solids @ full flow/Time" is calculated by multiplying the column headed "Weight of sample/Time" by the ratio of the flow in the ventilation duct to the flow in the sample train (1,506).

Conven. PP, Avg.(1&3)	0.34	0.19	0.29	0.44	0.49	0.84	1.54	1.84	4.05
PPI, Avg.(2,4-8)	0.24	0.26	0.32	0.32	0.39	0.42	0.54	0.71	2.18



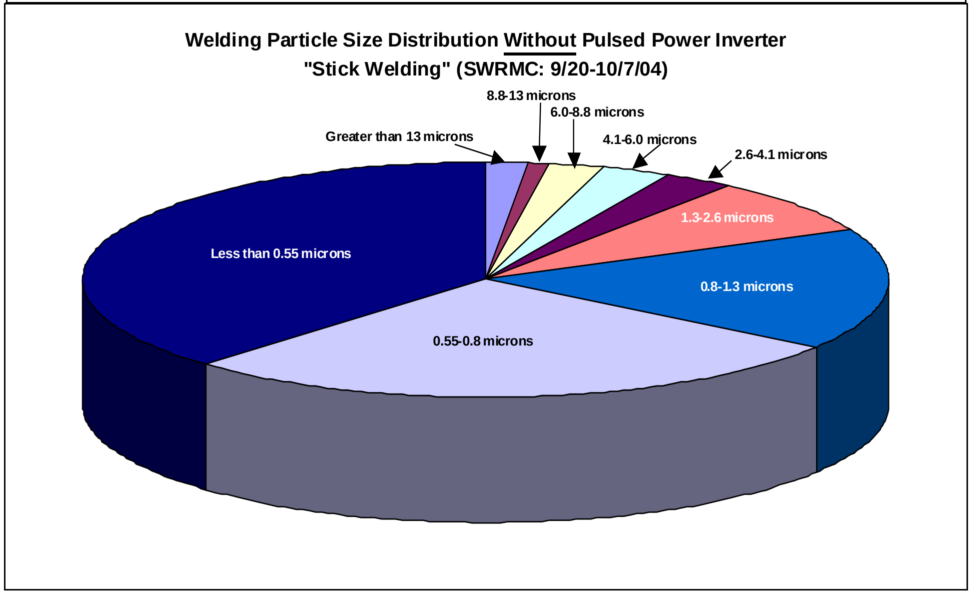


FIGURE F-6: Welding Particle Size Distribution- SWMRC

Table F-4: Southwest Regional Maintenance Center Impactor Weight Gain

WEIGHT GAINS FOR IMPACTOR STAGES @ SWRMC, San Diego, CA, Adjusted for blank weight loss (mg)

Sample No. (date)	Cascade Impactor Stage Number									Tot. Adjust. Wt. (mg)	Welding Time (min)	Wt/Time (mg/min)	Wt of solids @ full flow/Time	Total wire used/run (gm)	Total emissions/Wire used (mg/gm)
	1	2	3	4	5	6	7	8	9 (Filter)						
1(9/28/04)	0.04	0.00	0.54	0.44	0.44	1.14	2.74	3.64	5.10	14.08	53.33	0.26	407	569	38.11
2(9/28/04)	0.24	0.00	0.14	0.24	0.24	1.64	3.54	4.14	5.10	15.28	57.98	0.26	406	673	34.96
3(9/29/04)	0.34	0.04	0.44	0.54	0.54	1.94	3.94	4.14	5.90	17.82	60.08	0.30	457	722	38.01
4(9/29/04)	0.34	0.34	0.14	0.84	0.34	2.04	3.44	4.84	6.10	18.42	59.98	0.31	473	720	39.40
5(9/30/04)	0.74	0.54	0.44	0.54	0.34	0.74	0.74	0.74	2.30	7.12	53.93	0.13	203	1,643	6.67
6(10/1/04)	0.44	0.44	0.34	0.00	0.34	0.34	0.24	0.64	1.00	3.78	29.08	0.13	200	875	6.65
7(10/1/04)	0.14	0.14	0.54	0.44	0.54	0.44	0.44	0.54	1.50	4.72	45.90	0.10	158	1,710	4.25
8(10/4/04)	0.04	0.34	0.74	0.44	0.64	0.54	0.14	0.64	2.10	5.62	52.32	0.11	165	1,891	4.58
9(10/4/04)	0.00	0.24	0.34	0.54	0.14	0.44	0.54	0.74	1.82	4.80	55.60	0.09	133	1,866	3.96
10(10/5/04)	0.34	0.14	0.24	0.27	0.44	0.34	0.54	0.74	2.20	5.25	48.77	0.11	166	1,637	4.94
11(10/5/04)	0.54	0.24	0.34	0.54	0.84	0.84	0.54	0.94	2.00	6.82	54.75	0.12	192	1,838	5.71
12(10/6/04)	0.14	0.44	0.14	0.34	0.44	0.74	1.94	4.94	6.70	15.82	49.32	0.32	494	794	30.68
13(10/6/04)	0.54	0.04	0.14	0.54	0.44	0.94	2.54	5.44	4.80	15.42	54.52	0.28	436	794	29.91
14(10/7/04)	0.04	0.04	0.44	0.04	0.84	0.74	1.74	4.34	6.40	16.62	54.83	0.30	467	297	86.18
15(10/7/04)	0.44	0.34	0.94	0.74	0.64	0.94	2.44	5.64	8.30	20.42	69.63	0.29	452	400	78.62
Averages	**0.3**	**0.2**	**0.4**	**0.4**	**0.5**	**0.9**	**1.7**	**2.8**	**4.2**	**11.5**		**0.21**	**321**		**27.51**
Avg for wire	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.7	1.8	5.4		0.11	174		5.25
Avg for stick	0.3	0.2	0.4	0.5	0.5	1.3	2.8	4.6	6.3	16.7		0.29	449		46.98
% of Tot. Weight	**2.5**	**1.9**	**3.4**	**3.8**	**4.2**	**8.0**	**14.8**	**24.5**	**36.8**	**Standard Deviation:**		**0.094**	**145**		**26.68**
% for wire	5.88	5.46	7.82	7.27	8.61	9.66	8.34	13.07	33.90	Standard Deviation:		0.017	26		1.11
% for stick	1.58	0.93	2.18	2.78	2.93	7.56	16.67	27.73	37.65	Standard Deviation:		0.020	31		22.22

NOTE 1: All values in stages 1-8 have been adjusted for blank weight loss of 0.34 mg (i.e., values shown are 0.34 mg higher than actual weight gains.

NOTE 2: All adjusted values that were negative have been changed to zero.

NOTE 3: Runs 5-11 are wire-type, pulsed power inverter welding. Runs 1-4 and 12-15 are conventional "stick" welding (shaded rows).

NOTE 4: The column headed "Weight of solids @ full flow/Time" is calculated by multiplying the column headed "Weight of sample/Time" by the ratio of the flow in the ventilation duct to the flow in the sample train (1,540).

Appendix G
Metal Emissions by Species

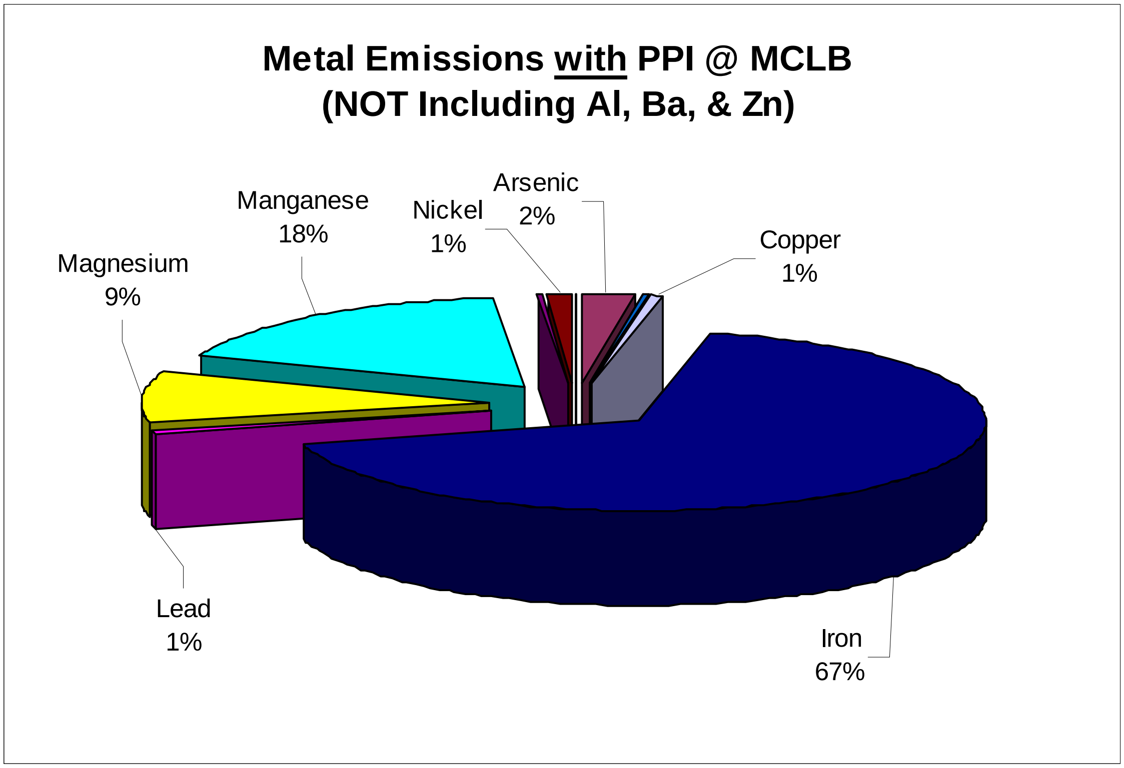


FIGURE G-1: Metal Emissions with PPI - MCLB

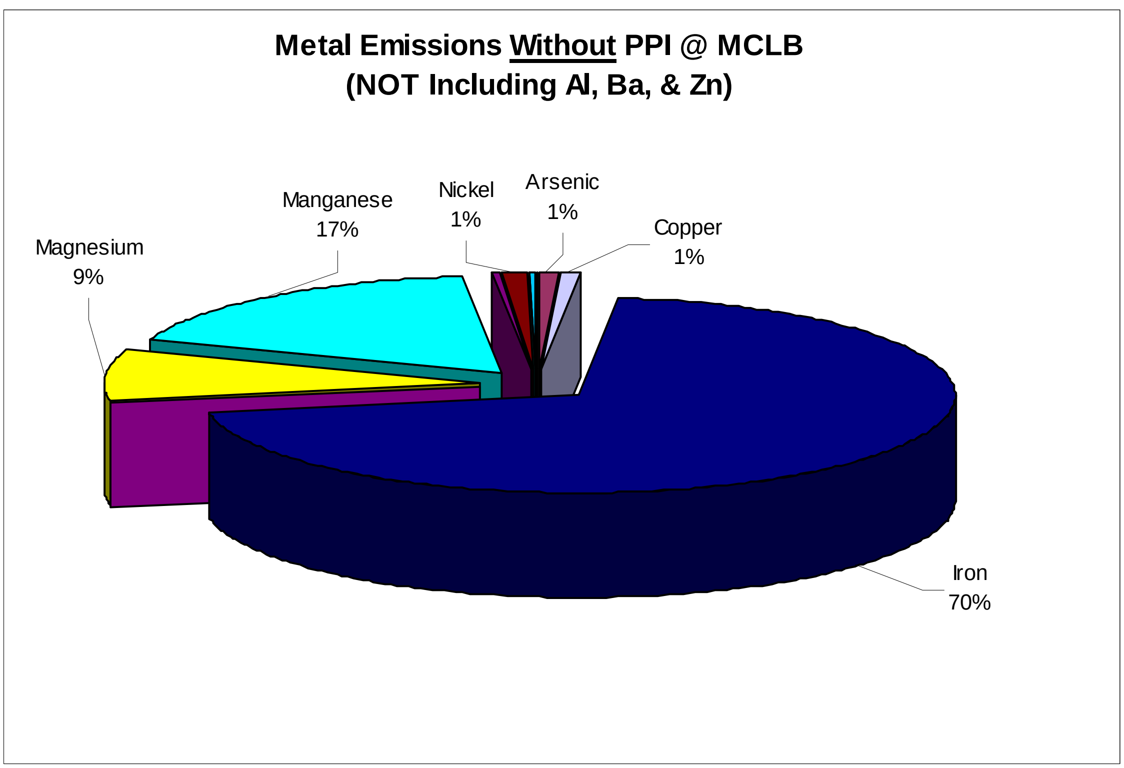


FIGURE G-2: Metal Emissions without PPI - MCLB

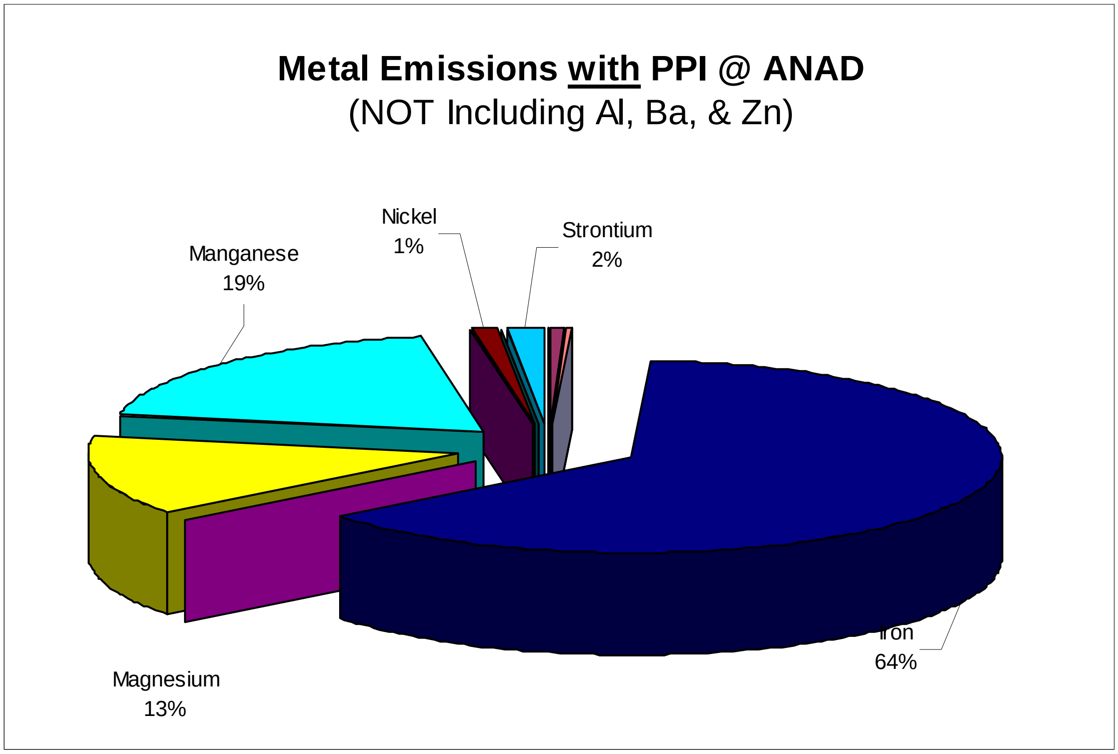


FIGURE G-3: Metal Emissions with PPI - ANAD

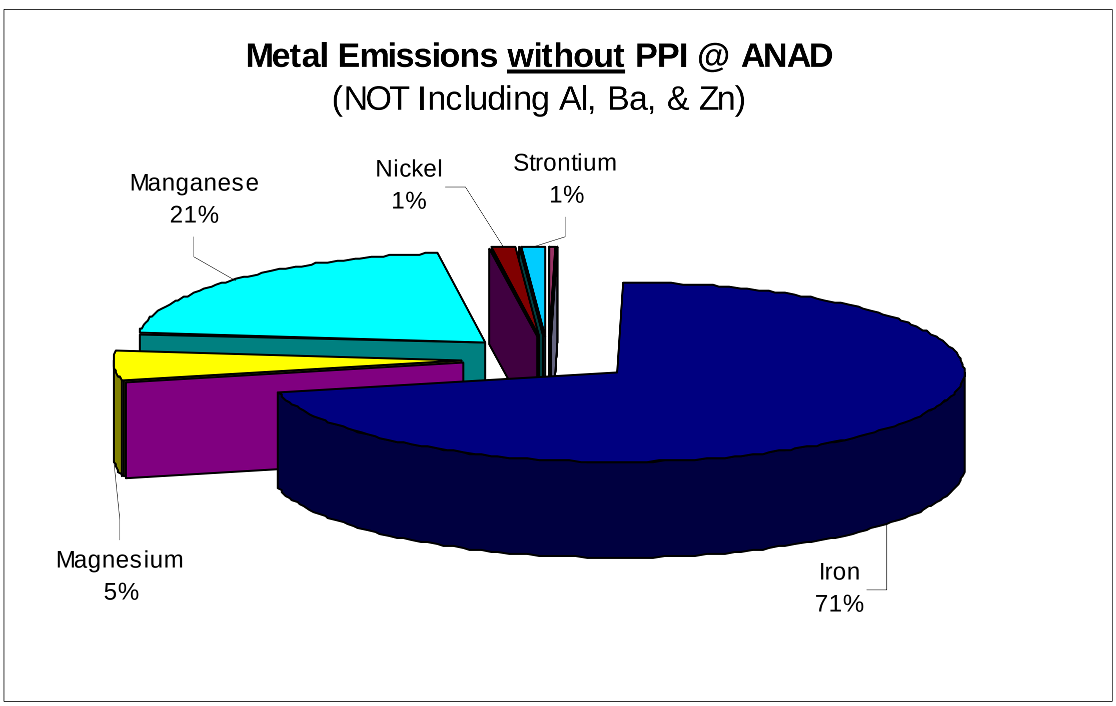


FIGURE G-4: Metal Emissions without PPI - ANAD

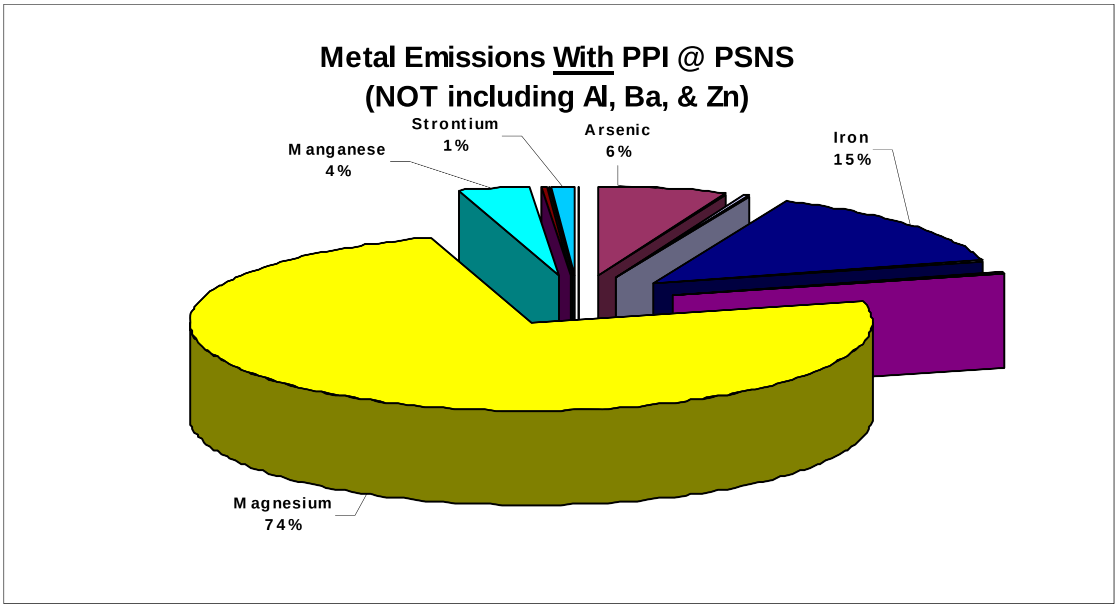


FIGURE G-5: Metal Emissions with PPI - PSNS

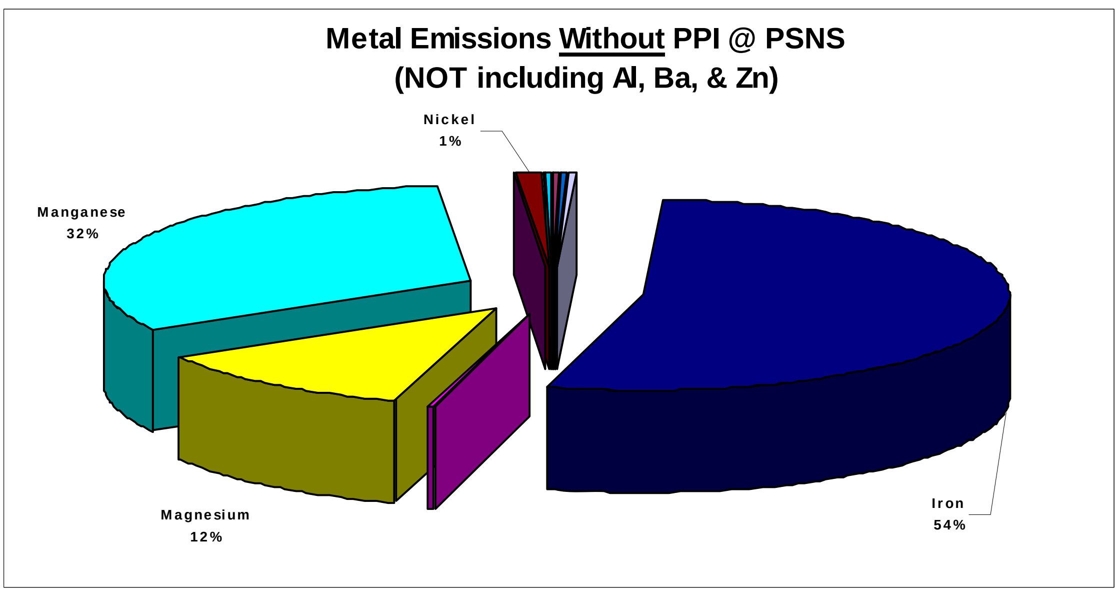


FIGURE G-6: Metal Emissions without PPI - PSNS

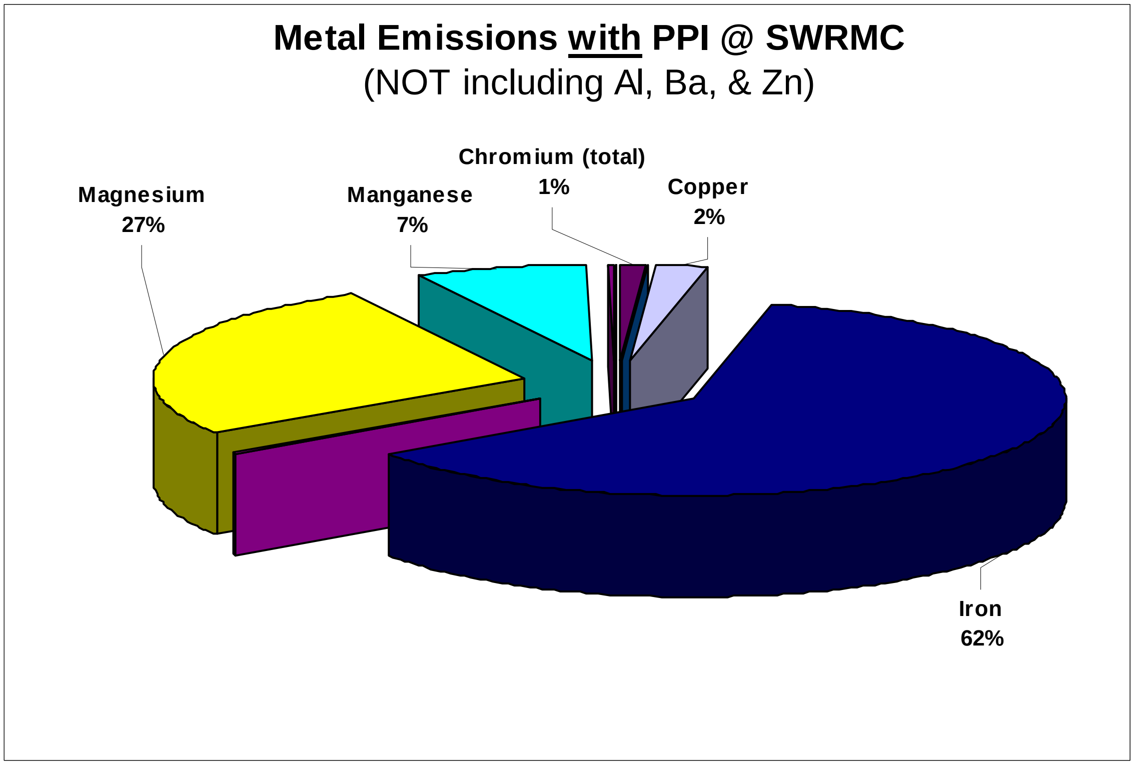


FIGURE G-7: Metal Emissions with PPI – SWRMC

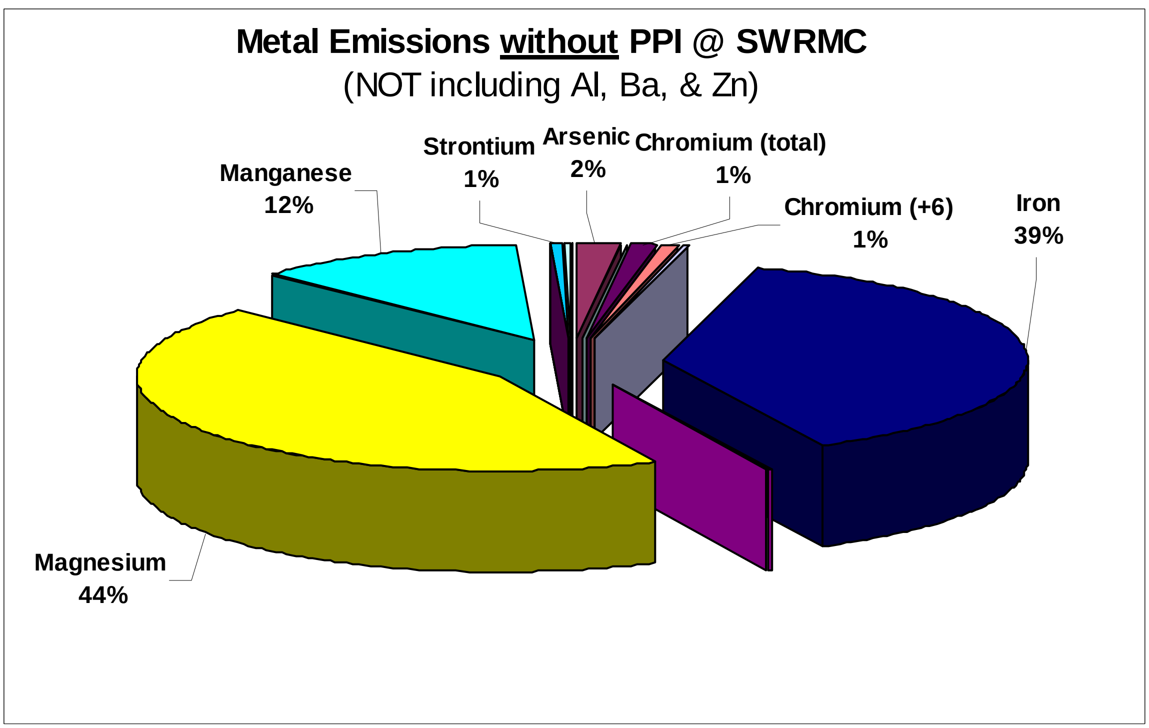


FIGURE G-8: Metal Emissions without PPI – SWRMC

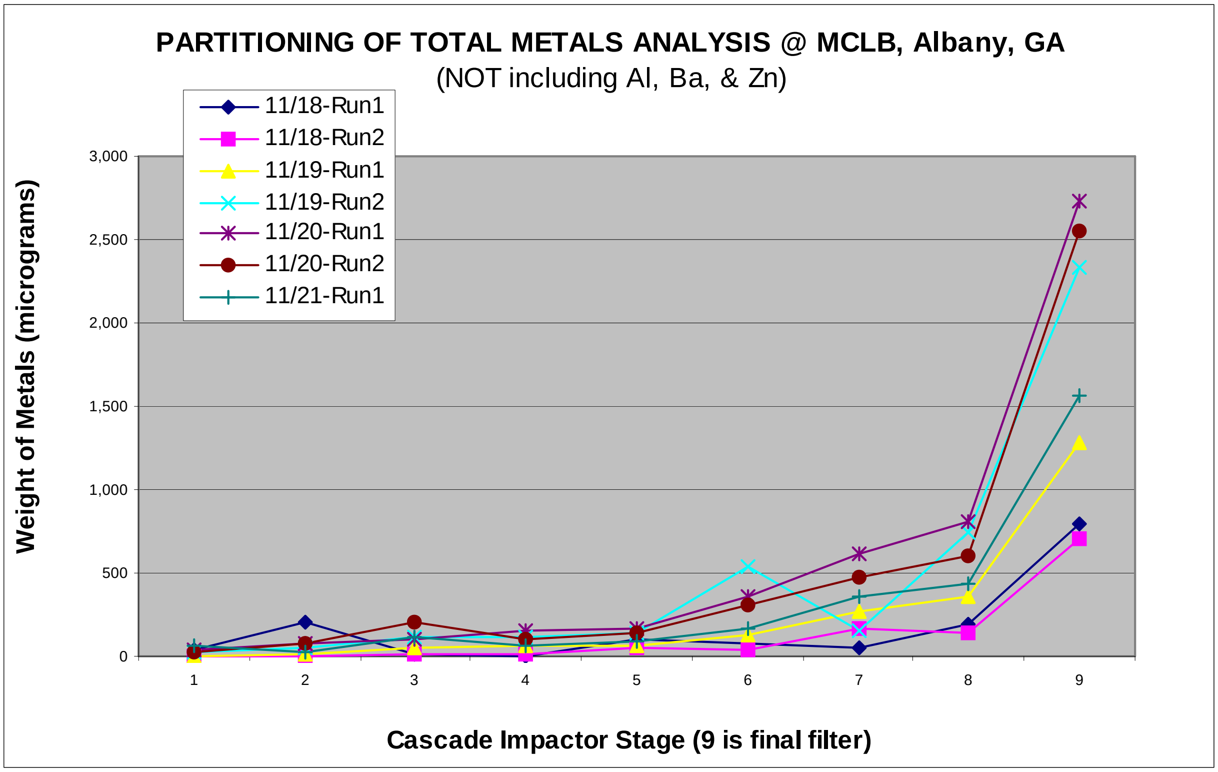


FIGURE G-9: Partitioning of Total Metals Analysis- MCLB

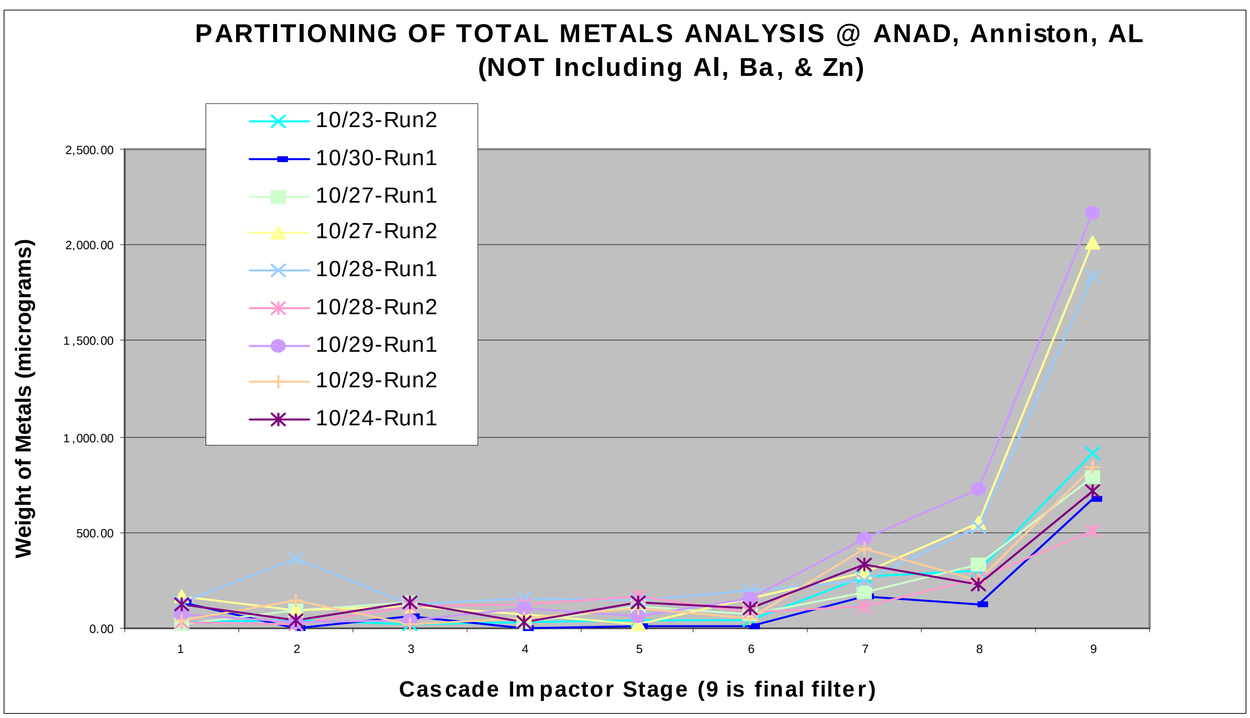


FIGURE G-10: Partitioning of Total Metals Analysis- ANAD

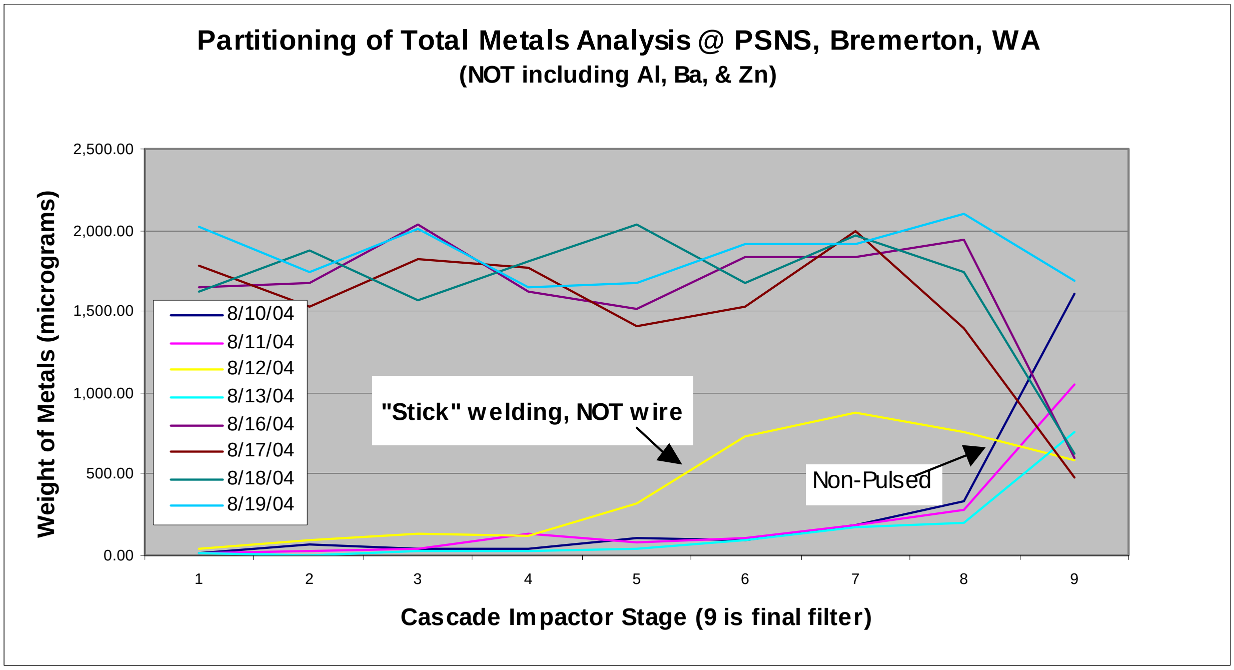


FIGURE G-11: Partitioning of Total Metals Analysis- PSNS

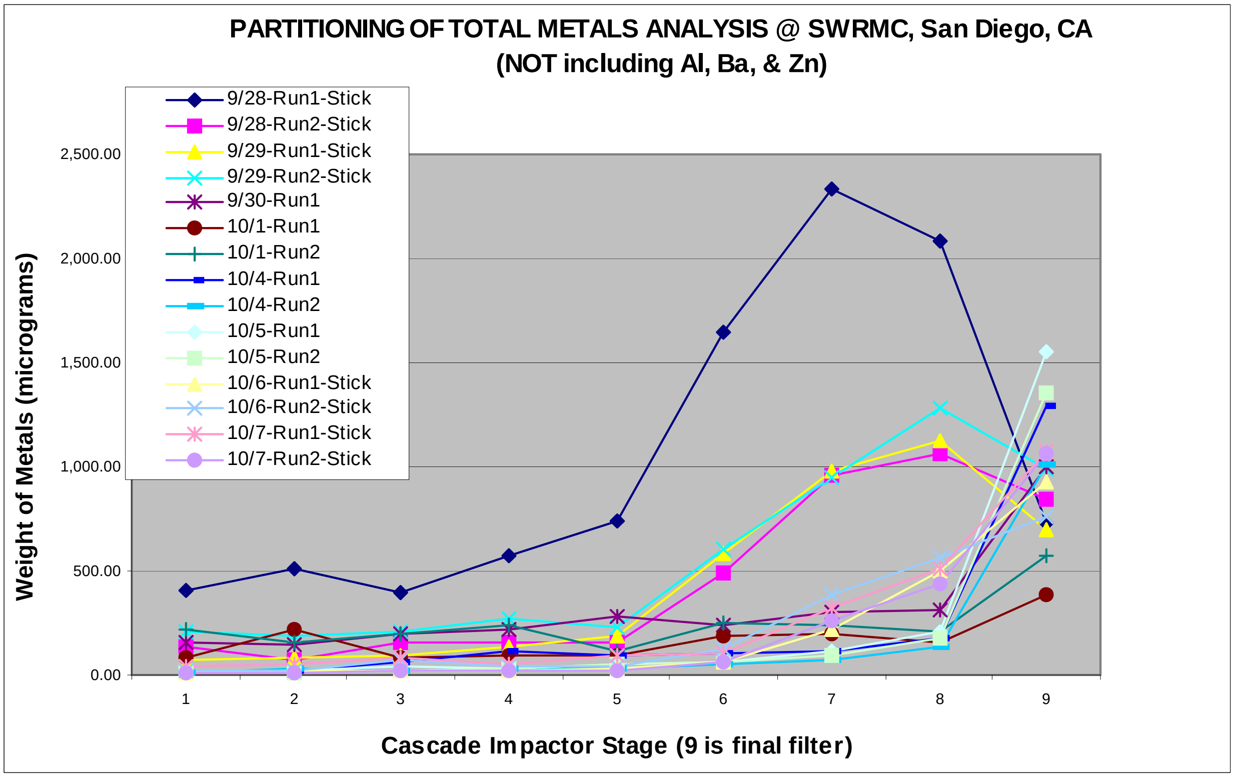


FIGURE G-12: Partitioning of Total Metals Analysis- SWRMC

Appendix H
Daily Metal Analyses Impactor Run

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, ANNISTON ARMY DEPOT (NOT Including Al, Ba, & Zn)

14 **30 October 03 - Run 1**

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	8.16	0.00	3.00	0.00	0.00	0.00	3.38	0.56	0.09	15.18
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.46	0.22	0.92	1.22	1.04	0.54	0.38	0.46	1.08	6.29
Chromium (+6)	0.00	0.08	0.06	0.05	0.04	0.05	0.06	0.06	0.04	0.44
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	17.44	0.00	13.44	0.00	5.44	1.44	23.44	13.44	22.30	96.96
Lead	0.21	0.00	0.11	0.00	0.05	0.03	0.15	0.11	0.27	0.90
Magnesium	99.67	0.00	39.67	0.00	0.00	0.00	119.67	99.67	643.50	1,002.17
Manganese	0.00	0.00	0.00	0.00	0.00	0.00	5.32	2.72	7.62	15.66
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.32	0.30	0.54	0.66	0.56	0.32	0.32	0.22	0.23	3.47
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	12.92	0.00	5.66	0.36	3.72	3.20	7.92	8.92	2.90	45.59
Vanadium	0.30	0.00	0.14	0.00	0.08	0.06	0.20	0.24	0.00	1.01
Total Metal Wt.	139.47	0.59	63.53	2.28	10.93	5.63	160.83	126.39	678.04	1,187.67
Gravimetric Data	40	40	0	0	340	240	740	1,540	4,500	7,440
Ratio of Total Metal Analysis To Gravimetric Data	3.49	0.01	na	na	0.03	0.02	0.22	0.08	0.15	0.16

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - AAD - 10/30-Run 1 (Al)

Wire Diameter (inch):	0.035	WireFeedRate(ft/min):	22.7
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	1,199
Flow Ratio (Duct/Probe):	1,444		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.00	0.00
1.10	0.03
0.00	0.00
0.00	0.00
0.45	0.01
0.03	0.00
0.00	0.00
0.00	0.00
7.01	0.21
0.07	0.00
72.44	2.15
1.13	0.03
0.00	0.00
0.25	0.01
0.00	0.00
0.00	0.00
3.30	0.10
0.07	0.00
85.85	**2.55**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, ANNISTON ARMY DEPOT (NOT Including Al, Ba, & Zn)

1 **21 October 03 - Run 1**

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.16	0.50
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	1.28	0.36	0.76	0.14	0.40	0.00	0.10	0.54	0.40	3.95
Chromium (+6)	0.314	0.042	0.232	0.058	0.082	0.000	0.112	0.076	0.110	1.03
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	2.28	0.00	0.00	2.28
Iron	699.44	81.44	739.44	33.44	179.44	29.44	125.44	49.44	76.30	2,013.85
Lead	0.69	0.00	0.59	0.00	0.00	0.00	0.00	0.00	0.00	1.27
Magnesium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	59.67	0.00	59.67
Manganese	218.92	22.92	164.92	13.52	64.92	15.52	46.92	12.72	25.02	585.37
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	12.34	1.36	13.54	0.70	3.14	0.78	2.54	0.86	1.33	36.59
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.12	1.68	0.00	0.16	0.34	0.00	0.00	6.32	0.00	8.61
Vanadium	0.24	0.06	0.04	0.00	0.08	0.00	0.00	0.18	0.00	0.59
Total Metal Wt.	933.33	107.86	919.51	48.01	248.40	45.74	177.39	130.14	103.33	2,713.71
Gravimetric Data	na	na	na	na	na	na	na	na	na	9,180
Ratio of Total Metal Analysis To Gravimetric Data	na	na	na	na	na	na	na	na	na	0.30

* Impactor stage filters assembled incorrectly.

** All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

*** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - AAD - 10/21 - Run 1

Wire Diameter (inch):	0.063	(flux)	WireFeedRate(ft/min):	14.2
Wire Density (lb/cu.ft):	490		Weld Time (seconds):	2,107
Flow Ratio (Duct/Probe):	1,444			

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.00	0.00
0.02	0.00
0.00	0.00
0.00	0.00
0.16	0.00
0.04	0.00
0.00	0.00
0.09	0.00
82.83	1.23
0.05	0.00
2.45	0.04
24.08	0.36
0.00	0.00
1.51	0.02
0.00	0.00
0.00	0.00
0.35	0.01
0.02	0.00
111.62	**1.66**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, ANNISTON ARMY DEPOT (NOT Including Al, Ba, & Zn)

2 **21 October 03 - Run 2**

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.08
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	4.04	0.30	0.32	0.06	0.00	0.08	0.08	0.04	0.16	5.05
Chromium (+6)	0.560	0.000	0.144	0.000	0.000	0.040	0.000	0.000	0.016	0.760
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	5.08	0.00	0.00	0.00	2.88	0.00	0.00	0.00	0.00	7.96
Iron	2,959.44	21.44	239.44	0.00	0.00	0.00	0.00	0.00	8.30	3,228.63
Lead	2.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.09
Magnesium	39.67	39.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	79.33
Manganese	918.92	3.72	88.92	0.34	0.92	1.12	0.52	0.54	1.22	1,016.21
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	59.94	0.56	4.34	0.22	0.22	0.14	0.18	0.16	0.37	66.13
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	7.92	0.00	0.00	0.00	0.00	0.00	0.70	0.00	8.62
Vanadium	1.32	0.20	0.08	0.00	0.00	0.00	0.00	0.00	0.00	1.60
Total Metal Wt.	3,991.05	73.80	333.24	0.61	4.02	1.37	0.77	1.43	10.15	4,416.46
Gravimetric Data	na	na	na	na	na	na	na	na	na	14,720
Ratio of Total Metal Analysis To Gravimetric Data	na	na	na	na	na	na	na	na	na	0.30

* Impactor stage filters assembled incorrectly.

** All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

*** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - AAD - 10/21 - Run 2

Wire Diameter (inch):	0.063	(flux)	WireFeedRate(ft/min):	14.2
Wire Density (lb/cu.ft):	490		Weld Time (seconds):	2,745
Flow Ratio (Duct/Probe):	1,444			

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.16	0.00
0.02	0.00
0.00	0.00
0.25	0.00
101.94	1.52
0.07	0.00
2.50	0.04
32.08	0.48
0.00	0.00
2.09	0.03
0.00	0.00
0.00	0.00
0.27	0.00
0.05	0.00
139.44	**2.07**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, ANNISTON ARMY DEPOT (NOT Including Al, Ba, & Zn)

3 **22 October 03 - Run 1**

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.80	2.96	0.00	1.20	0.40	5.36
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	2.04	0.60	1.14	0.32	0.36	0.38	0.24	0.36	0.20	5.61
Chromium (+6)	0.416	0.052	0.286	0.000	0.000	0.000	0.000	0.000	0.000	0.754
Cobalt	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.32
Copper	2.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.68
Iron	1,539.44	87.44	859.44	31.44	69.44	13.44	7.44	11.44	8.30	2,627.85
Lead	0.99	0.00	0.59	0.00	0.00	0.00	0.00	0.00	0.00	1.57
Magnesium	0.00	59.67	0.00	0.00	39.67	79.67	19.67	0.00	5.50	204.17
Manganese	418.92	20.92	258.92	7.12	16.52	1.32	0.70	1.12	0.82	726.35
Molybdenum	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21
Nickel	27.94	1.48	16.14	0.56	1.30	0.22	0.20	0.30	0.11	48.25
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	10.12	0.00	7.42	8.32	9.72	6.84	6.82	1.02	50.25
Vanadium	0.52	0.28	0.30	0.18	0.26	0.26	0.16	0.18	0.00	2.13
Total Metal Wt.	1,993.15	180.55	1,136.81	47.03	136.66	108.28	35.24	21.41	16.36	3,675.50
Gravimetric Data	na	na	na	na	na	na	na	na	na	10,920
Ratio of Total Metal Analysis To Gravimetric Data	na	na	na	na	na	na	na	na	na	0.34

* Impactor stage filters assembled incorrectly.

** All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

*** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - AAD - 10/22 - Run 1

Wire Diameter (inch):	0.063	(flux)	WireFeedRate(ft/min):	14.2
Wire Density (lb/cu.ft):	490		Weld Time (seconds):	1,804
Flow Ratio (Duct/Probe):	1,444			

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.00	0.00
0.26	0.00
0.00	0.00
0.00	0.00
0.27	0.00
0.04	0.00
0.02	0.00
0.13	0.00
126.25	1.88
0.08	0.00
9.81	0.15
34.89	0.52
0.01	0.00
2.32	0.03
0.00	0.00
0.00	0.00
2.41	0.04
0.10	0.00
176.58	**2.62**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, ANNISTON ARMY DEPOT (NOT Including Al, Ba, & Zn)

4 22 October 03 - Run 2

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.72	0.22	0.54	0.28	0.44	0.08	0.36	0.46	0.70	3.77
Chromium (+6)	0.000	0.000	0.136	0.000	0.130	0.124	0.154	0.190	0.286	1.020
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	33.44	25.44	299.44	47.44	319.44	113.44	299.44	419.44	820.30	2,377.85
Lead	0.05	0.11	0.17	0.07	0.11	0.00	0.09	0.11	0.51	1.19
Magnesium	0.00	19.67	0.00	0.00	0.00	0.00	0.00	0.00	15.50	35.17
Manganese	8.52	4.72	104.92	11.72	98.92	34.92	106.92	124.92	219.02	714.57
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	1.70	1.34	5.14	1.82	5.34	2.54	5.54	7.14	16.15	46.71
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	1.48	5.86	2.18	3.72	0.00	0.00	0.00	0.00	0.00	13.23
Vanadium	0.04	0.14	0.16	0.10	0.02	0.00	0.02	0.00	0.26	0.73
Total Metal Wt.	45.94	57.49	412.68	65.14	424.39	151.10	412.52	552.25	1,072.74	3,194.24
Gravimetric Data	na	na	na	na	na	na	na	na	na	9,280
Ratio of Total Metal Analysis To Gravimetric Data	na	na	na	na	na	na	na	na	na	0.34

* Impactor stage filters assembled incorrectly.
** All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.
*** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - AAD - 10/22 - Run 2

Wire Diameter (inch):	0.063	(flux)	WireFeedRate(ft/min):	14.2
Wire Density (lb/cu.ft):	490		Weld Time (seconds):	2,528
Flow Ratio (Duct/Probe):	1,444			

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.13	0.00
0.03	0.00
0.00	0.00
0.00	0.00
81.52	1.21
0.04	0.00
1.21	0.02
24.50	0.36
0.00	0.00
1.60	0.02
0.00	0.00
0.00	0.00
0.45	0.01
0.03	0.00
109.51	**1.63**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, ANNISTON ARMY DEPOT (NOT Including Al, Ba, & Zn)

5

23 October 03 - Run 1

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.34	0.60	0.48	0.88	0.42	0.60	0.50	0.08	0.56	4.43
Chromium (+6)	0.000	0.122	0.000	0.240	0.000	0.168	0.126	0.044	0.270	0.970
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	17.44	299.44	97.44	639.44	199.44	379.44	359.44	39.44	700.30	2,731.85
Lead	0.00	0.17	0.21	0.37	0.19	0.17	0.13	0.01	0.45	1.67
Magnesium	0.00	0.00	59.67	0.00	39.67	0.00	0.00	0.00	13.50	112.83
Manganese	5.52	100.92	22.92	186.92	70.92	128.92	140.92	13.72	185.02	855.77
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.70	5.14	1.54	10.74	2.94	6.34	5.34	0.94	13.35	47.03
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.76	7.72	1.54	5.92	0.28	0.00	0.00	0.00	16.21
Vanadium	0.00	0.14	0.26	0.24	0.22	0.16	0.14	0.00	0.26	1.41
Total Metal Wt.	24.00	407.28	190.23	840.36	319.71	516.07	506.59	54.23	913.72	3,772.17
Gravimetric Data	na	na	na	na	na	na	na	na	na	7,800
Ratio of Total Metal Analysis To Gravimetric Data	na	na	na	na	na	na	na	na	na	0.48

* Impactor stage filters assembled incorrectly.

** All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

*** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - AAD - 10/23 - Run 1

Wire Diameter (inch):	0.063	(flux)	WireFeedRate(ft/min):	14.2
Wire Density (lb/cu.ft):	490		Weld Time (seconds):	2,361
Flow Ratio (Duct/Probe):	1,444			

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.16	0.00
0.04	0.00
0.00	0.00
0.00	0.00
100.28	1.49
0.06	0.00
4.14	0.06
31.41	0.47
0.00	0.00
1.73	0.03
0.00	0.00
0.00	0.00
0.60	0.01
0.05	0.00
138.47	**2.06**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, ANNISTON ARMY DEPOT (NOT Including Al, Ba, & Zn)

6 **23 October 03 - Run 2**

	Cascade Impactor Stage									
	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	5.96	0.00	0.00	5.96
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.60	0.44	0.26	0.26	0.46	0.12	0.46	0.30	0.72	3.59
Chromium (+6)	0.000	0.000	0.000	0.000	0.000	0.000	0.048	0.092	0.180	0.320
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	23.44	33.44	17.44	25.44	31.44	35.44	121.44	219.44	680.30	1,187.85
Lead	0.03	0.01	0.00	0.03	0.07	0.03	0.21	0.13	0.63	1.11
Magnesium	0.00	0.00	0.00	0.00	0.00	0.00	99.67	0.00	41.50	141.17
Manganese	4.72	6.32	5.12	6.92	7.12	10.12	28.92	76.92	175.02	321.17
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.80	0.98	0.62	0.62	0.74	0.72	1.68	3.14	12.95	22.25
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	1.22	0.30	0.00	0.40	3.74	0.00	8.92	2.04	0.94	17.55
Vanadium	0.02	0.00	0.00	0.02	0.10	0.00	0.32	0.16	0.22	0.83
Total Metal Wt.	30.82	41.48	23.44	33.68	43.66	46.42	267.61	302.21	912.47	1,701.80
Gravimetric Data	240	240	140	0	40	240	0	940	2,200	4,040
Ratio of Total Metal Analysis To Gravimetric Data	0.13	0.17	0.17	na	1.09	0.19	na	0.32	0.41	0.42

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - AAD - 10/23 - Run 2				
Wire Diameter (inch):	0.063	(flux)	WireFeedRate(ft/min):	14.2
Wire Density (lb/cu.ft):	490		Weld Time (seconds):	965
Flow Ratio (Duct/Probe):	1,444			

Emissions/ Weld Time (mg/min)	Emissions/Wire Used (mg/gm)
0.00	0.00
0.54	0.01
0.00	0.00
0.00	0.00
0.32	0.00
0.03	0.00
0.00	0.00
0.00	0.00
106.68	1.59
0.10	0.00
12.68	0.19
28.84	0.43
0.00	0.00
2.00	0.03
0.00	0.00
0.00	0.00
1.58	0.02
0.07	0.00
152.84	2.27

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, ANNISTON ARMY DEPOT (NOT Including Al, Ba, & Zn)

7

24 October 03 - Run 1

	Cascade Impactor Stage									
	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Arsenic	5.10	0.00	2.64	0.00	1.40	3.22	0.00	0.00	0.00	12.35
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.60	0.48	0.54	0.32	0.38	0.24	0.42	0.46	0.52	3.93
Chromium (+6)	0.000	0.000	0.000	0.000	0.000	0.000	0.090	0.048	0.118	0.256
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	47.44	33.44	39.44	21.44	37.44	45.44	239.44	121.44	560.30	1,145.85
Lead	0.19	0.11	0.21	0.09	0.19	0.15	0.17	0.21	0.47	1.76
Magnesium	59.67	0.00	79.67	0.00	79.67	39.67	0.00	59.67	7.50	325.83
Manganese	4.12	4.92	4.72	3.92	5.92	10.52	84.92	32.92	133.02	284.97
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.78	0.74	0.66	0.54	0.60	0.78	3.74	1.88	11.15	20.87
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	5.74	5.72	9.72	5.76	9.12	5.44	1.58	8.32	0.00	51.39
Vanadium	0.20	0.18	0.30	0.18	0.24	0.18	0.18	0.28	0.00	1.73
Total Metal Wt.	123.90	45.58	137.89	32.24	134.95	105.63	330.53	225.21	713.09	1,849.01
Gravimetric Data	440	0	240	340	40	0	840	0	2,200	4,100
Ratio of Total Metal Analysis To Gravimetric Data	0.28	na	0.57	0.09	3.37	na	0.39	na	0.32	0.45

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - AAD - 10/24 - Run 1				
Wire Diameter (inch):	0.035	????	WireFeedRate(ft/min):	15.0
Wire Density (lb/cu.ft):	490		Weld Time (seconds):	931
Flow Ratio (Duct/Probe):	1,444			
Emissions/ Weld Time (mg/min)			Emissions/Wire Used (mg/gm)	
0.01			0.00	
1.15			0.05	
0.00			0.00	
0.00			0.00	
0.37			0.02	
0.02			0.00	
0.00			0.00	
0.00			0.00	
106.67			4.79	
0.16			0.01	
30.33			1.36	
26.53			1.19	
0.00			0.00	
1.94			0.09	
0.00			0.00	
0.00			0.00	
4.78			0.21	
0.16			0.01	
172.12			**7.72**	

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, ANNISTON ARMY DEPOT (NOT Including Al, Ba, & Zn)

8 **27 October 03 - Run 1**

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	4.70	1.40	0.00	2.92	0.00	2.14	0.00	0.12	11.28
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.64	0.46	0.54	0.26	0.34	0.26	0.28	0.42	0.80	3.97
Chromium (+6)	0.000	0.000	0.000	0.000	0.000	0.000	0.048	0.084	0.138	0.270
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	15.44	19.44	39.44	21.44	35.44	55.44	119.44	239.44	540.30	1,085.85
Lead	0.13	0.15	0.21	0.09	0.21	0.11	0.29	0.49	1.13	2.78
Magnesium	0.00	59.67	79.67	0.00	59.67	0.00	19.67	0.00	13.50	232.17
Manganese	1.72	2.12	4.72	4.32	5.52	17.12	36.92	86.92	219.02	378.37
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.58	0.48	0.68	0.60	0.56	1.06	1.72	3.34	9.35	18.37
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	6.00	7.92	11.32	3.12	8.52	2.84	4.98	5.22	0.06	49.97
Vanadium	0.18	0.24	0.32	0.10	0.26	0.10	0.22	0.24	0.36	2.01
Total Metal Wt.	24.68	95.17	138.29	29.92	113.43	76.92	185.69	336.14	784.79	1,785.02
Gravimetric Data	340	740	0	240	0	440	640	540	1,700	4,640
Ratio of Total Metal Analysis To Gravimetric Data	0.07	0.13	na	0.12	na	0.17	0.29	0.62	0.46	0.38

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - AAD - 10/27 - Run 1

Wire Diameter (inch):	0.063	(flux)	WireFeedRate(ft/min):	10.0
Wire Density (lb/cu.ft):	490		Weld Time (seconds):	1,303
Flow Ratio (Duct/Probe):	1,444			

Emissions/ Weld Time (mg/min)	Emissions/Wire Used (mg/gm)
0.00	0.00
0.75	0.02
0.00	0.00
0.00	0.00
0.26	0.01
0.02	0.00
0.00	0.00
0.00	0.00
72.22	1.52
0.18	0.00
15.44	0.33
25.17	0.53
0.00	0.00
1.22	0.03
0.00	0.00
0.00	0.00
3.32	0.07
0.13	0.00
118.73	**2.51**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, ANNISTON ARMY DEPOT (NOT Including Al, Ba, & Zn)

9

27 October 03 - Run 2

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	8.16	2.06	2.24	1.52	0.00	0.66	0.00	0.00	0.10	14.74
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.44	0.60	1.20	0.90	0.26	0.76	0.30	0.48	2.16	7.07
Chromium (+6)	0.000	0.000	0.000	0.000	0.000	0.076	0.108	0.140	0.238	0.562
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	27.44	35.44	55.44	53.44	9.44	123.44	219.44	439.44	1,500.30	2,463.85
Lead	0.29	0.25	0.25	0.33	0.00	0.27	0.19	0.39	2.09	4.03
Magnesium	119.67	39.67	39.67	0.00	0.00	0.00	0.00	0.00	25.50	224.50
Manganese	3.92	7.12	11.12	10.32	6.92	24.92	68.92	104.92	459.02	697.17
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.50	0.76	1.38	1.30	0.68	2.34	3.94	7.14	25.75	43.79
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	8.12	7.42	6.60	2.88	0.00	5.02	0.00	0.00	0.00	30.03
Vanadium	0.24	0.24	0.24	0.12	0.00	0.20	0.02	0.08	1.14	2.27
Total Metal Wt.	168.77	93.55	118.13	70.80	17.30	157.67	292.91	552.58	2,016.31	3,488.01
Gravimetric Data	40	540	140	340	440	540	940	1,540	4,700	9,220
Ratio of Total Metal Analysis To Gravimetric Data	4.22	0.17	0.84	0.21	0.04	0.29	0.31	0.36	0.43	0.38

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - AAD - 10/27 - Run 2

Wire Diameter (inch):	0.063	(flux)	WireFeedRate(ft/min):	12.1
Wire Density (lb/cu.ft):	490		Weld Time (seconds):	2,491
Flow Ratio (Duct/Probe):	1.444			

	Emissions/ Weld Time (mg/min)	Emissions/Wire Used (mg/gm)
Antimony	0.00	0.00
Arsenic	0.51	0.01
Beryllium	0.00	0.00
Cadmium	0.00	0.00
Chromium (total)	0.25	0.00
Chromium (+6)	0.02	0.00
Cobalt	0.00	0.00
Copper	0.00	0.00
Iron	85.72	1.50
Lead	0.14	0.00
Magnesium	7.81	0.14
Manganese	24.26	0.42
Molybdenum	0.00	0.00
Nickel	1.52	0.03
Selenium	0.00	0.00
Silver	0.00	0.00
Strontium	1.04	0.02
Vanadium	0.08	0.00
Total	**121.35**	**2.12**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, ANNISTON ARMY DEPOT (NOT Including Al, Ba, & Zn)

10 | **28 October 03 - Run 1**

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.08
Arsenic	0.36	0.00	1.84	0.78	1.38	0.00	7.36	0.00	0.00	11.71
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.50	0.52	1.16	1.02	0.92	0.66	0.90	0.56	1.34	7.55
Chromium (+6)	0.000	0.000	0.000	0.000	0.000	0.054	0.106	0.170	0.158	0.488
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	17.44	259.44	51.44	57.44	63.44	145.44	53.44	419.44	1,360.30	2,427.85
Lead	0.25	0.33	0.19	0.21	0.23	0.19	1.35	0.43	1.89	5.04
Magnesium	99.67	19.67	59.67	79.67	59.67	0.00	159.67	0.00	47.50	525.50
Manganese	2.52	78.92	8.52	10.12	11.52	42.92	7.72	102.92	399.02	664.17
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.42	3.94	1.12	1.10	1.20	2.34	0.94	6.54	23.75	41.35
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	9.52	2.74	5.08	7.42	5.70	2.56	12.32	0.90	0.00	46.23
Vanadium	0.24	0.16	0.16	0.24	0.18	0.16	0.38	0.20	0.64	2.35
Total Metal Wt.	130.91	365.71	129.17	157.99	144.23	194.31	244.25	531.15	1,834.61	3,732.31
Gravimetric Data	240	240	240	640	340	940	640	1,640	4,900	9,820
Ratio of Total Metal Analysis To Gravimetric Data	0.55	1.52	0.54	0.25	0.42	0.21	0.38	0.32	0.37	0.38

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - AAD - 10/28 - Run 1

Wire Diameter (inch):	0.063	(flux)	WireFeedRate(ft/min):	12.1
Wire Density (lb/cu.ft):	490		Weld Time (seconds):	2,175
Flow Ratio (Duct/Probe):	1,444			

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.00	0.00
0.47	0.01
0.00	0.00
0.00	0.00
0.30	0.01
0.02	0.00
0.00	0.00
0.00	0.00
96.74	1.69
0.20	0.00
20.94	0.37
26.47	0.46
0.00	0.00
1.65	0.03
0.00	0.00
0.00	0.00
1.84	0.03
0.09	0.00
148.72	**2.60**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, ANNISTON ARMY DEPOT (NOT Including Al, Ba, & Zn)

11

28 October 03 - Run 2

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	2.58	1.56	4.76	1.64	3.26	5.42	0.12	19.33
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.94	0.56	0.88	0.94	0.96	0.64	0.22	0.32	0.38	5.81
Chromium (+6)	0.000	0.000	0.000	0.000	0.000	0.000	0.044	0.066	0.138	0.248
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	23.44	13.44	43.44	43.44	45.44	45.44	81.44	129.44	380.30	805.85
Lead	0.09	0.13	0.19	0.19	0.21	0.17	0.21	0.33	1.03	2.52
Magnesium	0.00	0.00	59.67	59.67	99.67	19.67	0.00	79.67	15.50	333.83
Manganese	3.12	3.12	4.32	4.12	4.52	8.32	24.92	38.92	107.02	198.37
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.88	0.60	0.90	0.92	0.92	0.88	1.20	1.76	6.55	14.61
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	3.66	0.00	6.84	8.92	10.12	7.04	4.10	7.50	0.00	48.17
Vanadium	0.10	0.00	0.18	0.24	0.30	0.20	0.16	0.30	0.24	1.71
Total Metal Wt.	32.22	17.84	118.99	119.99	166.89	83.99	115.54	263.71	511.28	1,430.44
Gravimetric Data	340	0	140	340	0	140	40	140	1,700	2,840
Ratio of Total Metal Analysis To Gravimetric Data	0.09	na	0.85	0.35	na	0.60	2.89	1.88	0.30	0.50

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - AAD - 10/28 - Run 2

Wire Diameter (inch):	0.063	(flux)	WireFeedRate(ft/min):	14.2
Wire Density (lb/cu.ft):	490		Weld Time (seconds):	1,372
Flow Ratio (Duct/Probe):	1,444			

	Emissions/ Weld Time (mg/min)	Emissions/Wire Used (mg/gm)
Antimony	0.00	0.00
Arsenic	1.22	0.02
Beryllium	0.00	0.00
Cadmium	0.00	0.00
Chromium (total)	0.37	0.01
Chromium (+6)	0.02	0.00
Cobalt	0.00	0.00
Copper	0.00	0.00
Iron	50.90	0.76
Lead	0.16	0.00
Magnesium	21.09	0.31
Manganese	12.53	0.19
Molybdenum	0.00	0.00
Nickel	0.92	0.01
Selenium	0.00	0.00
Silver	0.00	0.00
Strontium	3.04	0.05
Vanadium	0.11	0.00
Total Metal Wt.	**90.36**	**1.35**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, ANNISTON ARMY DEPOT (NOT Including Al, Ba, & Zn)

12

29 October 03 - Run 1

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	3.88	0.00	0.00	2.22	0.00	0.00	0.00	0.76	0.08	6.94
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.46	0.50	0.34	0.50	0.48	0.30	0.56	0.74	1.76	5.61
Chromium (+6)	0.138	0.000	0.068	0.000	0.000	0.062	0.000	0.260	0.278	0.806
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	19.44	21.44	29.44	47.44	45.44	115.44	279.44	439.44	1,220.30	2,217.85
Lead	0.13	0.05	0.13	0.15	0.07	0.11	0.27	0.37	1.23	2.48
Magnesium	39.67	0.00	0.00	39.67	0.00	0.00	59.67	99.67	75.50	314.17
Manganese	3.12	4.52	5.92	8.92	11.52	36.92	116.92	174.92	459.02	821.77
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.56	0.68	0.66	0.82	0.96	1.94	4.34	6.94	21.75	38.65
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	4.76	2.66	4.24	7.28	3.46	2.40	5.02	6.20	1.36	37.37
Vanadium	0.14	0.06	0.12	0.24	0.12	0.12	0.28	0.38	0.74	2.19
Total Metal Wt.	72.28	29.90	40.91	107.23	62.04	157.28	466.49	729.67	1,782.03	3,447.82
Gravimetric Data	0	240	240	0	240	340	0	1,440	4,200	6,700
Ratio of Total Metal Analysis To Gravimetric Data	na	0.12	0.17	na	0.26	0.46	na	0.51	0.42	0.51

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - AAD - 10/29 - Run 1

Wire Diameter (inch):	0.063	(flux)	WireFeedRate(ft/min):	14.2
Wire Density (lb/cu.ft):	490		Weld Time (seconds):	2,371
Flow Ratio (Duct/Probe):	1,444			

Emissions/Weld Time (mg/min)	Emissions/Wire Used (mg/gm)
0.00	0.00
0.25	0.00
0.00	0.00
0.00	0.00
0.20	0.00
0.03	0.00
0.00	0.00
0.00	0.00
81.07	1.21
0.09	0.00
11.48	0.17
30.04	0.45
0.00	0.00
1.41	0.02
0.00	0.00
0.00	0.00
1.37	0.02
0.08	0.00
126.03	**1.88**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, ANNISTON ARMY DEPOT (NOT Including Al, Ba, & Zn)

13 29 October 03 - Run 2

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.12
Arsenic	0.28	4.30	0.00	0.00	1.68	0.00	8.56	0.00	0.00	14.81
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.66	0.50	0.26	0.26	0.32	0.14	0.52	0.20	0.68	3.51
Chromium (+6)	0.000	0.000	0.000	0.000	0.000	0.044	0.068	0.090	0.138	0.340
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	11.44	21.44	13.44	21.44	25.44	39.44	115.44	179.44	580.30	1,007.85
Lead	0.13	0.19	0.11	0.11	0.15	0.03	0.37	0.15	0.61	1.82
Magnesium	19.67	99.67	0.00	19.67	59.67	0.00	239.67	0.00	33.50	471.83
Manganese	1.52	2.32	2.52	3.32	4.12	12.92	28.92	70.92	219.02	345.57
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.56	0.44	0.32	0.34	0.40	0.70	1.54	2.54	9.15	15.99
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	5.68	11.32	6.08	7.92	9.72	2.54	16.32	0.00	0.30	59.87
Vanadium	0.12	0.32	0.16	0.16	0.22	0.06	0.48	0.08	0.42	2.01
Total Metal Wt.	40.05	140.49	22.88	53.21	101.71	55.86	411.99	253.41	844.13	1,923.72
Gravimetric Data	340	140	40	0	40	140	440	540	1,700	3,380
Ratio of Total Metal Analysis To Gravimetric Data	0.12	1.00	0.57	na	2.54	0.40	0.94	0.47	0.50	0.57

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - AAD - 10/29 - Run 2

Wire Diameter (inch):	0.063	(flux)	WireFeedRate(ft/min):	12.3
Wire Density (lb/cu.ft):	490		Weld Time (seconds):	1,277
Flow Ratio (Duct/Probe):	1,444			

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.01	0.00
1.01	0.02
0.00	0.00
0.00	0.00
0.24	0.00
0.02	0.00
0.00	0.00
0.00	0.00
68.40	1.18
0.12	0.00
32.02	0.55
23.45	0.40
0.00	0.00
1.09	0.02
0.00	0.00
0.00	0.00
4.06	0.07
0.14	0.00
130.56	**2.25**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, MARINE CORPS LOGISTICS BASE (NOT Including Al, Ba, & Zn)

15 **21 November 03 - Run 1**

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.30	0.26	0.32	0.24	0.26	0.20	0.32	0.36	0.00	2.24
Arsenic	9.16	5.54	8.76	4.00	5.76	3.06	7.36	8.56	0.31	52.50
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.00	0.00	0.00	0.02	0.02	0.08	0.26	0.36	1.96	2.68
Chromium (+6)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.118	0.118
Cobalt	0.00	0.00	1.72	0.00	0.00	0.00	0.00	0.00	0.24	1.96
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.56	17.56
Iron	15.84	23.64	52.44	48.24	74.24	137.24	279.44	325.44	1,188.30	2,144.85
Lead	0.17	0.13	0.21	0.09	0.15	0.11	0.25	0.23	0.85	2.16
Magnesium	35.67	0.00	51.67	0.00	0.00	0.00	5.67	27.67	0.00	120.67
Manganese	1.32	1.72	3.32	4.52	8.12	20.92	56.92	66.92	319.02	482.77
Molybdenum	0.00	0.00	0.19	0.21	0.29	0.45	0.63	0.65	6.40	8.82
Nickel	0.24	0.68	1.14	1.12	1.52	2.54	4.54	5.14	25.75	42.67
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.12
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Metal Wt.	62.69	31.96	119.76	58.43	90.35	164.59	355.38	435.32	1,560.64	2,879.11
Gravimetric Data	240	90	150	220	230	530	730	860	2,830	5,880
Ratio of Total Metal Analysis To Gravimetric Data	0.26	0.36	0.80	0.27	0.39	0.31	0.49	0.51	0.55	0.49

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - MCLB - 11/21 - Run1

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	14.2
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	3,853
Flow Ratio (Duct/Probe):	1,444		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.05	0.00
1.18	0.03
0.00	0.00
0.00	0.00
0.06	0.00
0.00	0.00
0.04	0.00
0.39	0.01
48.24	1.39
0.05	0.00
2.71	0.08
10.86	0.31
0.20	0.01
0.96	0.03
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
64.76	**1.86**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, MARINE CORPS LOGISTICS BASE (NOT Including Al, Ba, & Zn)

1 16 September 03 - Run 1

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.16	0.14	0.08	0.10	0.00	0.00	0.08	0.00	0.00	0.55
Arsenic	0.36	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.52
Beryllium										
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.26	0.26	0.00	0.04	0.00	0.04	0.10	0.00	0.72	1.40
Chromium (+6)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.00	0.72	0.00	0.48	0.00	0.22	0.08	0.00	5.80	7.31
Iron	2.64	76.44	0.00	37.04	0.00	6.84	10.64	0.00	20.30	153.9
Lead	0.09	0.09	0.01	0.03	0.00	0.00	0.05	0.00	0.21	0.46
Magnesium										
Manganese	0.14	18.92	0.84	10.72	0.08	3.52	2.92	0.00	2.82	39.95
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.24	1.14	0.00	0.46	0.24	0.28	0.24	0.00	0.37	2.97
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	1.72	0.00	0.00	0.00	0.00	0.00	1.12	0.00	0.00	2.84
Vanadium	0.06	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.10
Total Metal Wt.	5.66	97.70	0.92	49.02	0.32	10.90	15.26	0.00	30.23	210.00
Gravimetric Data	na	na	na	na	na	na	na	na	na	440
Ratio of Total Metal Analysis To Gravimetric Data	na	na	na	na	na	na	na	na	na	0.48

* Impactor stage filters assembled incorrectly.
** All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.
*** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - MCLB - 9/16 - Run 1

Wire Diameter (inch):	0.035	WireFeedRate(ft/min):	16.8
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	654
Flow Ratio (Duct/Probe):	1,444		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.07	0.00
0.07	0.00
0.00	0.00
0.00	0.00
0.19	0.01
0.00	0.00
0.00	0.00
0.97	0.04
20.40	0.82
0.06	0.00
0.00	0.00
5.29	0.21
0.00	0.00
0.39	0.02
0.00	0.00
0.00	0.00
0.38	0.02
0.01	0.00
27.83	**1.12**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, MARINE CORPS LOGISTICS BASE (NOT Including Al, Ba, & Zn)
2 **16 September 03 - Run 2**

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.14	0.12	0.14	0.20	0.20	0.24	0.28	0.14	0.00	1.44
Arsenic	0.76	0.00	0.00	1.56	1.56	3.36	4.76	0.00	0.00	11.99
Beryllium										
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.10	0.32	0.12	0.22	0.12	0.20	0.18	0.14	0.00	1.37
Chromium (+6)	0.046	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.046
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	3.08	1.38	0.12	0.48	0.12	0.32	0.14	0.00	0.80	6.45
Iron	2.44	115.04	3.04	58.24	9.44	49.84	37.84	3.64	22.90	302.4
Lead	0.09	0.11	0.07	0.13	0.09	0.17	0.17	0.09	0.00	0.89
Magnesium										
Manganese	0.26	30.92	1.52	14.12	2.12	11.32	7.52	1.12	7.82	76.71
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.00	1.46	0.18	0.68	0.16	0.56	0.36	0.16	0.21	3.77
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	3.32	1.52	1.32	4.72	4.52	5.92	5.52	4.52	0.00	31.35
Vanadium	0.10	0.04	0.04	0.14	0.14	0.18	0.18	0.14	0.00	0.95
Total Metal Wt.	10.32	150.90	6.54	80.48	18.46	72.10	56.94	9.94	31.74	437.40
Gravimetric Data	na	na	na	na	na	na	na	na	na	1,950
Ratio of Total Metal Analysis To Gravimetric Data	na	na	na	na	na	na	na	na	na	0.22

* Impactor stage filters assembled incorrectly.
** All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.
*** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - MCLB - 9/16 - Run 2

Wire Diameter (inch):	0.035	WireFeedRate(ft/min):	16.8
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	1,770
Flow Ratio (Duct/Probe):	1,444		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.07	0.00
0.59	0.02
0.00	0.00
0.00	0.00
0.07	0.00
0.00	0.00
0.00	0.00
0.32	0.01
14.81	0.60
0.04	0.00
0.00	0.00
3.76	0.15
0.00	0.00
0.18	0.01
0.00	0.00
0.00	0.00
1.53	0.06
0.05	0.00
21.42	**0.86**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, MARINE CORPS LOGISTICS BASE (NOT Including Al, Ba, & Zn)

3 **16 September 03 - Run 3**

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.10	0.12	0.08	0.00	0.00	0.29
Arsenic	0.00	0.00	0.00	0.00	0.56	0.96	0.00	0.00	0.00	1.52
Beryllium										
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.00	0.20	0.02	0.12	0.00	0.02	0.00	0.00	0.12	0.46
Chromium (+6)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.044	0.058	0.102
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.16	1.56	0.12	1.06	2.28	0.12	0.12	0.00	0.74	6.17
Iron	0.00	121.24	0.00	107.04	0.00	14.24	4.24	0.00	32.10	278.9
Lead	0.00	0.00	0.00	0.01	0.03	0.05	0.00	0.00	0.01	0.09
Magnesium										
Manganese	0.28	34.92	2.12	30.92	0.46	5.12	3.72	0.56	10.42	88.51
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.18	1.76	0.18	1.32	0.00	0.26	0.18	0.00	0.37	4.25
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Metal Wt.	0.62	159.68	2.44	140.46	3.42	20.88	8.34	0.60	43.83	380.27
Gravimetric Data	na	na	na	na	na	na	na	na	na	3,940
Ratio of Total Metal Analysis To Gravimetric Data	na	na	na	na	na	na	na	na	na	0.10

* Impactor stage filters assembled incorrectly.

** All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

*** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - MCLB - 9/16 - Run 3

Wire Diameter (inch):	0.035	**WireFeedRate(ft/min):**	16.8
Wire Density (lb/cu.ft):	490	**Weld Time (seconds):**	2,549
Flow Ratio (Duct/Probe):	1,444		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.01	0.00
0.05	0.00
0.00	0.00
0.00	0.00
0.02	0.00
0.00	0.00
0.00	0.00
0.21	0.01
9.48	0.38
0.00	0.00
0.00	0.00
3.01	0.12
0.00	0.00
0.14	0.01
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
12.93	**0.52**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, MARINE CORPS LOGISTICS BASE (NOT Including Al, Ba, & Zn)

4

17 September 03 - Run 1

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.24	0.00	0.00	0.10	0.00	0.00	0.18	0.10	0.00	0.61
Arsenic	0.16	0.00	0.00	0.00	0.00	0.00	3.36	0.00	0.00	3.52
Beryllium										
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.06	0.00	0.00	0.00	0.00	0.06	0.14	0.02	0.22	0.48
Chromium (+6)	0.000	0.000	0.046	0.000	0.000	0.000	0.000	0.048	0.000	0.094
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.44	0.26	0.08	0.00	0.00	1.02	0.00	0.00	1.34	3.15
Iron	0.00	0.00	0.00	0.00	0.00	110.24	11.24	0.00	85.30	206.8
Lead	0.03	0.01	0.00	0.00	0.33	0.00	0.13	0.01	0.01	0.50
Magnesium										
Manganese	0.28	1.52	0.52	2.12	1.52	34.92	1.52	0.12	25.02	67.53
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.00	0.00	0.00	0.00	0.00	1.38	0.14	0.00	0.93	2.45
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.92	0.00	0.00	0.00	0.00	0.00	3.32	0.00	0.00	4.24
Vanadium	0.02	0.02	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.16
Total Metal Wt.	2.13	1.80	0.65	2.22	1.84	147.62	20.14	0.29	112.83	289.51
Gravimetric Data	na	na	na	na	na	na	na	na	na	3,230
Ratio of Total Metal Analysis To Gravimetric Data	na	na	na	na	na	na	na	na	na	0.09

* Impactor stage filters assembled incorrectly.

** All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

*** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - MCLB - 9/17 - Run 1

Wire Diameter (inch):	0.035	WireFeedRate(ft/min):	15.0
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	2,073
Flow Ratio (Duct/Probe):	1,444		

Emissions/ Weld Time (mg/min)	Emissions/Wire Used (mg/gm)
0.03	0.00
0.15	0.01
0.00	0.00
0.00	0.00
0.02	0.00
0.00	0.00
0.00	0.00
0.13	0.01
8.65	0.39
0.02	0.00
0.00	0.00
2.82	0.13
0.00	0.00
0.10	0.00
0.00	0.00
0.00	0.00
0.18	0.01
0.01	0.00
12.10	**0.54**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, MARINE CORPS LOGISTICS BASE (NOT Including Al, Ba, & Zn)

5 **17 September 03 - Run 2**

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.12	0.08	0.00	0.00	0.00	0.00	0.00	0.19
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beryllium										
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.82	0.84
Chromium (+6)	0.044	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.036	0.080
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.40	0.12	0.10	0.26	0.12	0.70	0.36	0.42	6.80	9.29
Iron	0.0	0.0	0.0	0.0	4.2	72.8	40.2	8.0	624.3	749.7
Lead	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.17	0.18
Magnesium										
Manganese	0.36	2.92	1.72	1.92	4.12	22.92	12.92	4.92	199.02	250.81
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.00	0.20	0.00	0.14	0.22	0.98	0.56	0.30	7.55	9.95
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Metal Wt.	0.80	3.24	1.94	2.40	8.70	97.44	54.08	13.70	838.71	1,021.02
Gravimetric Data	na	na	na	na	na	na	na	na	na	4,760
Ratio of Total Metal Analysis To Gravimetric Data	na	na	na	na	na	na	na	na	na	0.21

* Impactor stage filters assembled incorrectly.

** All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

*** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - MCLB - 9/17 - Run 2

Wire Diameter (inch):	0.035	WireFeedRate(ft/min):	15.0
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	2,405
Flow Ratio (Duct/Probe):	1,444		

Emissions/ Weld Time (mg/min)	Emissions/Wire Used (mg/gm)
0.01	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.03	0.00
0.00	0.00
0.00	0.00
0.33	0.02
27.02	1.21
0.01	0.00
0.00	0.00
9.04	0.41
0.00	0.00
0.36	0.02
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
36.79	**1.65**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, MARINE CORPS LOGISTICS BASE (NOT Including Al, Ba, & Zn)

6 **17 September 03 - Run 3**

Cascade Impactor Stage

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total of All Stages**
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.12
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beryllium										
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.00	0.14	0.02	0.20	0.00	0.00	0.02	0.00	0.54	0.90
Chromium (+6)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.40	1.68	0.44	2.28	0.10	1.00	0.44	0.52	4.00	10.87
Iron	0.0	121.6	0.6	209.4	0.0	47.0	54.2	14.6	370.3	818.0
Lead	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.13	0.14
Magnesium										
Manganese	0.52	32.92	2.72	58.92	2.32	15.92	15.12	7.12	123.02	258.57
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.00	1.52	0.20	2.54	0.16	0.72	0.66	0.36	4.35	10.51
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	23.64	0.00	23.64
Total Metal Wt.	0.92	157.90	4.02	273.38	2.58	64.68	70.60	46.28	502.35	1,122.72
Gravimetric Data	na	na	na	na	na	na	na	na	na	3,423
Ratio of Total Metal Analysis To Gravimetric Data	na	na	na	na	na	na	na	na	na	0.33

* Impactor stage filters assembled incorrectly.
** All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.
*** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - MCLB - 9/17 - Run 3

Wire Diameter (inch):	0.035	WireFeedRate(ft/min):	15.0
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	2,525
Flow Ratio (Duct/Probe):	1,444		

Emissions/ Weld Time (mg/min)	**Emissions/ Wire Used (mg/gm)**
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.03	0.00
0.00	0.00
0.00	0.00
0.37	0.02
28.08	1.26
0.00	0.00
0.00	0.00
8.88	0.40
0.00	0.00
0.36	0.02
0.00	0.00
0.00	0.00
0.00	0.00
0.81	0.04
38.54	**1.73**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, MARINE CORPS LOGISTICS BASE (NOT Including Al, Ba, & Zn)

7 **18 September 03 - Run 1**

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.14	0.12	0.10	0.00	0.35
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.17
Beryllium										
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.48	0.00	0.04	0.00	0.22	0.00	0.00	0.00	0.12	0.85
Chromium (+6)	0.000	0.106	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.106
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	3.28	0.24	2.28	0.30	1.88	0.00	0.28	0.38	1.14	9.79
Iron	339.4	0.0	78.6	0.0	199.4	0.0	0.0	0.0	6.5	624.0
Lead	0.07	0.00	0.03	0.00	0.03	0.01	0.00	0.01	0.03	0.16
Magnesium										
Manganese	86.92	0.44	22.92	0.20	52.92	1.12	0.92	1.92	1.62	168.97
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	4.14	0.00	1.04	0.00	2.34	0.00	0.00	0.00	0.07	7.59
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Metal Wt.	434.32	0.79	104.94	0.50	256.82	1.26	1.32	2.40	9.66	812.02
Gravimetric Data	na	na	na	na	na	na	na	na	na	1,990
Ratio of Total Metal Analysis To Gravimetric Data	na	na	na	na	na	na	na	na	na	0.41

* Impactor stage filters assembled incorrectly.

** All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

*** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - MCLB - 9/18 - Run 1

Wire Diameter (inch):	0.035	WireFeedRate(ft/min):	16.7
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	2,717
Flow Ratio (Duct/Probe):	1,444		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.01	0.00
0.01	0.00
0.00	0.00
0.00	0.00
0.03	0.00
0.00	0.00
0.00	0.00
0.31	0.01
19.91	0.80
0.01	0.00
0.00	0.00
5.39	0.22
0.00	0.00
0.24	0.01
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
25.90	**1.05**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, MARINE CORPS LOGISTICS BASE (NOT Including Al, Ba, & Zn)

8 **18 September 03 - Run 2**

	Cascade Impactor Stage									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total of All Stages**
Antimony	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.12	0.00	0.29
Arsenic	0.00	0.00	0.00	0.96	0.00	0.00	0.00	0.76	0.00	1.72
Beryllium										
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.04	0.00	0.00	0.02	0.00	0.00	0.04	0.14	0.82	1.04
Chromium (+6)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.70	0.16	0.20	0.26	0.52	0.36	1.04	0.78	5.20	9.23
Iron	2.2	0.0	7.4	11.0	39.0	25.2	126.6	108.6	526.3	846.6
Lead	0.01	0.00	0.00	0.07	0.00	0.00	0.00	0.09	0.23	0.39
Magnesium										
Manganese	2.12	1.52	4.12	3.12	13.72	9.92	36.92	26.92	163.02	261.37
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.18	0.16	0.26	0.22	0.64	0.50	1.60	1.16	6.15	10.87
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Metal Wt.	5.28	1.84	12.02	15.86	53.92	36.02	166.24	138.60	701.73	1,131.52
Gravimetric Data	na	na	na	na	na	na	na	na	na	3,360
Ratio of Total Metal Analysis To Gravimetric Data	na	na	na	na	na	na	na	na	na	0.34

* Impactor stage filters assembled incorrectly.

** All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

*** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - MCLB - 9/18 - Run 2

Wire Diameter (inch):	0.035	WireFeedRate(ft/min):	16.7
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	2,792
Flow Ratio (Duct/Probe):	1,444		

Emissions/ Weld Time (mg/min)	Emissions/Wire Used (mg/gm)
0.01	0.00
0.05	0.00
0.00	0.00
0.00	0.00
0.03	0.00
0.00	0.00
0.00	0.00
0.29	0.01
26.28	1.06
0.01	0.00
0.00	0.00
8.11	0.33
0.00	0.00
0.34	0.01
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
35.12	**1.42**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, MARINE CORPS LOGISTICS BASE (NOT Including Al, Ba, & Zn)

9 **18 November 03 - Run 1**

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.24	0.50	0.12	0.00	0.20	0.00	0.00	0.12	0.00	1.17
Arsenic	9.16	15.36	0.88	0.00	10.96	1.02	0.00	9.76	0.49	47.62
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.04	0.24	0.02	0.00	0.18	0.08	0.00	0.14	1.36	2.04
Chromium (+6)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.044	0.138	0.182
Cobalt	0.20	0.00	0.00	0.00	0.00	0.00	0.44	0.94	0.50	2.08
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.02	11.02
Iron	21.44	45.04	16.04	1.24	88.04	72.04	36.44	104.24	576.30	960.85
Lead	0.17	0.37	0.01	0.00	0.19	0.00	0.00	49.69	0.65	51.06
Magnesium	0.00	143.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	143.67
Manganese	1.32	2.12	1.12	0.70	3.72	5.12	7.92	24.92	193.02	239.95
Molybdenum	0.00	0.00	0.00	0.00	0.43	0.39	0.19	0.29	1.72	3.02
Nickel	0.52	0.62	0.70	0.50	1.52	1.34	0.88	1.48	8.15	15.71
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.52	1.52
Vanadium	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Total Metal Wt.	33.08	207.94	18.88	2.44	105.23	79.99	45.87	191.61	794.88	1,479.92
Gravimetric Data	0	50	50	0	220	0	60	0	100	480
Ratio of Total Metal Analysis To Gravimetric Data	na	4.16	0.38	na	0.48	na	0.76	na	7.95	3.08

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - MCLB - 11/18 - Run 1

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	16.3
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	3,577
Flow Ratio (Duct/Probe):	1,444		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.03	0.00
1.15	0.03
0.00	0.00
0.00	0.00
0.05	0.00
0.00	0.00
0.05	0.00
0.27	0.01
23.28	0.58
1.24	0.03
3.48	0.09
5.81	0.15
0.07	0.00
0.38	0.01
0.00	0.00
0.00	0.00
0.04	0.00
0.00	0.00
35.86	**0.90**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, MARINE CORPS LOGISTICS BASE (NOT Including Al, Ba, & Zn)

10 **18 November 03 - Run 2**

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.38	0.00	0.44	0.38	0.00	0.00	1.19
Arsenic	0.00	0.00	0.00	12.76	0.62	15.76	11.36	3.88	0.21	44.59
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.00	0.00	0.00	0.02	0.00	0.08	0.10	0.00	0.96	1.15
Chromium (+6)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.052	0.138	0.190
Cobalt	0.24	0.42	0.30	0.00	0.00	0.24	0.00	0.26	0.32	1.78
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.14	12.14
Iron	0.00	0.00	6.24	40.84	20.24	60.64	64.24	44.64	640.30	877.16
Lead	0.00	0.00	0.00	0.25	0.01	0.33	0.27	0.05	0.83	1.72
Magnesium	0.00	0.00	0.00	73.67	0.00	125.67	69.67	0.00	0.00	269.00
Manganese	0.14	0.92	1.32	2.72	2.32	6.72	14.72	16.52	279.02	324.39
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.74	0.74
Nickel	0.00	0.24	0.40	0.50	0.46	0.62	0.70	0.74	8.15	11.81
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vanadium	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.02
Total Metal Wt.	0.38	1.58	8.26	131.13	23.65	210.50	161.43	66.14	942.82	1,545.88
Gravimetric Data	260	30	300	90	210	0	340	110	1,530	2,870
Ratio of Total Metal Analysis To Gravimetric Data	0.00	0.05	0.03	1.46	0.11	na	0.47	0.60	0.62	0.54

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - MCLB - 11/18 - Run 2

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	16.3
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	3,671
Flow Ratio (Duct/Probe):	1,444		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.03	0.00
1.05	0.03
0.00	0.00
0.00	0.00
0.03	0.00
0.00	0.00
0.04	0.00
0.29	0.01
20.71	0.52
0.04	0.00
6.35	0.16
7.66	0.19
0.02	0.00
0.28	0.01
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
36.50	**0.91**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, MARINE CORPS LOGISTICS BASE (NOT Including Al, Ba, & Zn)

11

19 November 03 - Run 1

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.10	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.17
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.21
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.00	0.00	0.04	0.02	0.04	0.08	0.24	0.28	1.56	2.24
Chromium (+6)	0.000	0.000	0.000	0.000	0.000	0.044	0.000	0.040	0.118	0.202
Cobalt	0.00	0.00	0.00	0.40	0.00	0.24	0.00	0.00	0.30	0.94
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.40	17.40
Iron	0.00	13.44	41.44	53.44	59.44	105.44	219.44	279.44	980.30	1,752.40
Lead	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.31	0.34
Magnesium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Manganese	0.68	1.72	3.32	4.72	6.92	17.32	44.92	68.92	259.02	407.53
Molybdenum	0.00	0.00	0.19	0.27	0.25	0.33	0.35	0.43	4.60	6.42
Nickel	0.24	0.52	0.98	1.04	1.14	1.72	2.94	4.14	18.75	31.47
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Metal Wt.	1.02	15.68	45.97	59.89	67.79	125.17	267.99	353.25	1,282.57	2,219.32
Gravimetric Data	50	120	410	40	360	230	600	80	2,260	4,150
Ratio of Total Metal Analysis To Gravimetric Data	0.02	0.13	0.11	1.50	0.19	0.54	0.45	4.42	0.57	0.53

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - MCLB - 11/19 - Run 1

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	16.6
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	1,813
Flow Ratio (Duct/Probe):	1.444		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.01	0.00
0.01	0.00
0.00	0.00
0.00	0.00
0.11	0.00
0.01	0.00
0.04	0.00
0.83	0.02
83.77	2.06
0.02	0.00
0.00	0.00
19.48	0.48
0.31	0.01
1.50	0.04
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
106.09	**2.61**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, MARINE CORPS LOGISTICS BASE (NOT Including Al, Ba, & Zn)

12

19 November 03 - Run 2

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.16	0.16	0.14	0.20	0.20	0.58	0.00	0.42	0.00	1.84
Arsenic	2.96	4.16	1.76	4.36	4.96	19.56	0.00	0.00	0.53	38.28
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.02	0.00	0.10	0.10	0.12	0.36	0.00	0.76	3.36	4.80
Chromium (+6)	0.000	0.000	0.000	0.000	0.000	0.000	0.062	0.078	0.158	0.298
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.28	0.50
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.48	22.00	27.48
Iron	19.44	41.44	99.44	101.44	121.44	239.44	119.44	519.44	1,740.30	3,001.85
Lead	0.07	0.05	0.05	0.11	0.09	0.51	0.00	0.35	1.01	2.21
Magnesium	0.00	0.00	0.00	0.00	0.00	237.67	0.00	73.67	0.00	311.33
Manganese	1.32	2.72	5.52	7.32	11.52	32.92	26.92	140.92	519.02	748.17
Molybdenum	0.00	0.17	0.47	0.37	0.41	0.63	0.21	0.83	9.00	12.09
Nickel	0.52	1.02	2.34	1.94	2.14	3.54	1.86	7.14	33.75	54.25
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.52	0.84
Vanadium	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.10
Total Metal Wt.	24.48	49.71	109.81	115.83	140.87	535.61	148.71	749.08	2,329.93	4,204.03
Gravimetric Data	310	0	530	260	560	550	1,150	1,460	3,770	8,590
Ratio of Total Metal Analysis To Gravimetric Data	0.08	na	0.21	0.45	0.25	0.97	0.13	0.51	0.62	0.49

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - MCLB - 11/19 - Run 2

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	16.6
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	3,623
Flow Ratio (Duct/Probe):	1,444		

Emissions/ Weld Time (mg/min)	Emissions/Wire Used (mg/gm)
0.04	0.00
0.92	0.02
0.00	0.00
0.00	0.00
0.11	0.00
0.01	0.00
0.01	0.00
0.66	0.02
71.81	1.76
0.05	0.00
7.45	0.18
17.90	0.44
0.29	0.01
1.30	0.03
0.00	0.00
0.00	0.00
0.02	0.00
0.00	0.00
100.57	**2.47**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, MARINE CORPS LOGISTICS BASE (NOT Including Al, Ba, & Zn)

13 — 20 November 03 - Run 1

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.32	0.32	0.24	0.36	0.24	0.38	0.30	0.46	0.00	2.60
Arsenic	7.76	7.76	4.16	9.56	5.30	9.76	7.76	12.16	0.56	64.77
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.00	0.00	0.06	0.10	0.18	0.38	0.60	0.74	3.56	5.60
Chromium (+6)	0.000	0.000	0.000	0.000	0.000	0.000	0.060	0.060	0.178	0.298
Cobalt	0.00	0.00	0.00	0.00	0.30	0.00	0.22	0.00	0.40	0.92
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.18	27.60	32.78
Iron	17.04	50.04	84.84	95.84	144.84	269.44	477.44	563.44	2,120.30	3,823.25
Lead	0.15	0.13	0.11	0.17	0.09	0.19	0.19	0.29	0.85	2.14
Magnesium	11.67	15.67	0.00	41.67	0.00	33.67	15.67	91.67	0.00	210.00
Manganese	1.72	3.12	4.92	7.12	13.12	38.92	100.92	120.92	519.02	809.77
Molybdenum	0.00	0.21	0.41	0.45	0.69	1.01	1.03	1.05	11.60	16.45
Nickel	0.38	1.22	2.34	2.14	3.14	4.94	6.94	8.34	43.75	73.19
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Metal Wt.	39.03	78.46	97.07	157.40	167.89	358.68	611.12	804.30	2,727.83	5,041.76
Gravimetric Data	130	260	420	260	500	410	1,120	450	4,780	8,330
Ratio of Total Metal Analysis To Gravimetric Data	0.30	0.30	0.23	0.61	0.34	0.87	0.55	1.79	0.57	0.61

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - MCLB - 11/20 - Run 1

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	15.7
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	3,626
Flow Ratio (Duct/Probe):	1,444		

Emissions/ Weld Time (mg/min)	Emissions/Wire Used (mg/gm)
0.06	0.00
1.55	0.04
0.00	0.00
0.00	0.00
0.13	0.00
0.01	0.00
0.02	0.00
0.78	0.02
91.38	2.38
0.05	0.00
5.02	0.13
19.35	0.50
0.39	0.01
1.75	0.05
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
120.51	**3.13**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, MARINE CORPS LOGISTICS BASE (NOT Including Al, Ba, & Zn)

14

20 November 03 - Run 2

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.26	0.26	0.38	0.24	0.24	0.38	0.28	0.32	0.00	2.34
Arsenic	6.76	6.56	12.16	2.84	3.52	9.36	3.76	4.92	0.45	50.32
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.00	0.06	0.10	0.04	0.08	0.22	0.40	0.56	3.16	4.59
Chromium (+6)	0.000	0.000	0.000	0.044	0.000	0.064	0.064	0.094	0.178	0.444
Cobalt	0.76	0.26	0.00	0.38	0.28	0.00	0.24	0.20	0.32	2.44
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.80	24.80
Iron	19.44	60.64	105.44	84.24	121.84	215.44	373.44	467.44	1,954.30	3,402.25
Lead	0.13	0.11	0.23	0.11	0.09	0.21	0.15	0.17	0.93	2.10
Magnesium	0.00	0.00	75.67	0.00	0.00	49.67	0.00	0.00	0.00	125.33
Manganese	2.52	3.92	6.72	7.92	12.32	32.92	82.92	116.92	519.02	785.17
Molybdenum	0.00	0.21	0.43	0.39	0.53	0.75	0.93	1.05	11.40	15.69
Nickel	0.46	1.18	2.54	2.14	2.74	3.94	6.34	7.34	41.75	68.43
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Metal Wt.	30.32	73.19	203.66	98.33	141.63	312.94	468.51	599.00	2,556.32	4,483.90
Gravimetric Data	520	270	250	390	410	720	880	1,040	4,300	8,780
Ratio of Total Metal Analysis To Gravimetric Data	0.06	0.27	0.81	0.25	0.35	0.43	0.53	0.58	0.59	0.51

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - MCLB - 11/20 - Run 2

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	15.7
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	3,610
Flow Ratio (Duct/Probe):	1,444		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.06	0.00
1.21	0.03
0.00	0.00
0.00	0.00
0.11	0.00
0.01	0.00
0.06	0.00
0.60	0.02
81.68	2.12
0.05	0.00
3.01	0.08
18.85	0.49
0.38	0.01
1.64	0.04
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
107.65	**2.80**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, PUGET SOUND NAVAL SHIPYARD

8

19 August 2004
(NOT Including Aluminum, Barium, and Zinc)
Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	1.78	1.38	1.58	1.58	1.38	1.58	1.58	0.90	0.00	11.76
Arsenic	135.00	119.00	135.00	109.00	109.00	121.00	115.00	121.00	0.70	964.70
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.65	0.75	0.91	0.73	0.85	0.77	0.57	0.59	0.00	5.82
Chromium (+6)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.19	0.29
Cobalt	0.00	0.00	0.00	0.00	0.00	0.46	0.00	0.00	0.00	0.46
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	133.40	118.00	148.80	138.60	134.00	180.80	236.80	344.80	760.00	2,195.20
Lead	1.85	1.45	1.65	1.65	1.45	1.45	1.45	1.07	0.00	12.02
Magnesium	1,706.00	1,466.00	1,686.00	1,358.00	1,388.00	1,546.00	1,446.00	1,426.00	69.00	12,091.00
Manganese	9.47	9.27	11.87	14.87	16.27	35.67	87.67	197.67	859.00	1,241.76
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.74	1.04	1.00	1.18	1.16	0.58	0.78	0.90	2.58	9.96
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	25.20	21.20	23.20	21.20	21.20	21.20	19.20	13.20	0.00	165.60
Vanadium	1.05	0.85	1.01	0.89	0.83	0.89	0.89	0.73	0.66	7.80
Total Metal Wt.	2,015.14	1,738.94	2,011.02	1,647.70	1,674.14	1,910.40	1,909.94	2,106.97	1,692.13	16,706.37
Gravimetric Data	440	540	440	440	740	740	740	1,540	6,100	11,720
Ratio of Total Metal Analysis To Gravimetric Data	4.58	3.22	4.57	3.74	2.26	2.58	2.58	1.37	0.28	1.43

* All data are two times laboratory-reported value to account for cutting filters in half for lab. analysis.
** All data have been corrected by subtracting average PSNS 2nd week blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - PSNS - 8/19 - Run 1

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	18.8
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	2,881
Flow Ratio (Duct/Probe):	1.506		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.37	0.01
30.25	0.66
0.00	0.00
0.00	0.00
0.18	0.00
0.01	0.00
0.01	0.00
0.00	0.00
68.83	1.49
0.38	0.01
379.12	8.23
38.94	0.85
0.00	0.00
0.31	0.01
0.00	0.00
0.00	0.00
5.19	0.11
0.24	0.01
523.84	**11.38**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, PUGET SOUND NAVAL SHIPYARD

1

10 August 2004
(NOT Including Aluminum, Barium, and Zinc)
Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.02	0.00	0.00	0.04	0.00	0.06	0.00	0.00	0.12
Arsenic	0.00	0.00	0.00	0.00	1.40	0.00	2.40	0.00	0.30	4.10
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.24	0.28	0.20	0.24	0.30	0.24	0.30	0.36	1.30	3.46
Chromium (+6)	0.00	0.00	0.04	0.04	0.05	0.06	0.08	0.14	0.37	0.78
Cobalt	0.46	0.56	0.30	0.80	0.22	0.64	0.00	0.26	0.30	3.54
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.60	6.60
Iron	10.90	18.70	21.50	25.70	41.30	46.90	79.30	190.90	903.52	1,338.72
Lead	0.00	0.08	0.00	0.02	0.08	0.02	0.12	0.18	1.28	1.78
Magnesium	0.00	47.10	9.90	0.00	57.10	22.50	67.10	26.30	77.80	307.80
Manganese	3.84	3.64	4.44	5.84	8.84	18.24	39.44	115.44	599.54	799.26
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.82	0.78	0.88	0.92	1.00	1.00	1.56	3.40	19.20	29.56
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.90	0.00	0.00	0.90	0.10	0.90	0.00	0.00	2.80
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.68	0.90
Total Metal Wt.	16.26	72.06	37.26	33.56	111.23	89.70	191.26	337.20	1,610.89	2,499.42
Gravimetric Data	440	140	140	240	440	340	340	1,140	5,200	8,420
Ratio of Total Metal Analysis To Gravimetric Data	0.04	0.51	0.27	0.14	0.25	0.26	0.56	0.30	0.31	0.30

* All data are two times laboratory-reported value to account for cutting filters in half for lab. analysis.

** All data have been corrected by subtracting average PSNS 1st week blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - PSNS - 8/10 - Run 1

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	15.1
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	2,400
Flow Ratio (Duct/Probe):	1,506		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.00	0.00
0.15	0.00
0.00	0.00
0.00	0.00
0.13	0.00
0.03	0.00
0.13	0.00
0.25	0.01
50.39	1.36
0.07	0.00
11.59	0.31
30.08	0.81
0.00	0.00
1.11	0.03
0.00	0.00
0.00	0.00
0.11	0.00
0.03	0.00
94.08	**2.54**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, PUGET SOUND NAVAL SHIPYARD

2

11 August 2004
(NOT Including Aluminum, Barium, and Zinc)
Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.06
Arsenic	0.00	0.00	0.00	3.20	0.60	0.00	0.00	0.00	0.84	4.64
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.00	0.24	0.00	0.24	0.28	0.26	0.24	0.30	0.74	2.30
Chromium (+6)	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.10	0.22
Cobalt	0.00	0.22	0.00	0.00	0.26	0.00	0.00	0.24	0.58	1.30
Copper	0.00	0.00	0.00	0.00	0.00	0.00	6.60	10.00	44.00	60.60
Iron	10.50	9.30	20.50	38.90	37.50	71.50	154.50	240.90	879.52	1,463.12
Lead	0.00	0.14	0.02	0.12	0.04	0.04	0.00	0.00	0.88	1.24
Magnesium	0.00	14.70	14.50	81.10	32.30	21.90	0.00	0.00	0.00	164.50
Manganese	1.02	0.82	1.22	2.24	3.04	8.04	21.44	27.44	125.54	190.80
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	1.40	0.22	0.50	0.38	0.56	0.34	0.54	0.60	1.52	6.06
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.10	0.10	1.30	0.50	0.10	0.00	0.00	0.00	2.10
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Metal Wt.	12.92	25.74	36.84	127.54	75.08	102.18	183.38	279.54	1,053.72	1,896.94
Gravimetric Data	240	340	340	340	540	540	640	640	2,000	5,620
Ratio of Total Metal Analysis To Gravimetric Data	0.05	0.08	0.11	0.38	0.14	0.19	0.29	0.44	0.53	0.34

* All data are two times laboratory-reported value to account for cutting filters in half for lab. analysis.

** All data have been corrected by subtracting average PSNS 1st week blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - PSNS - 8/11 - Run 1

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	16.7
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	2,763
Flow Ratio (Duct/Probe):	1,506		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.00	0.00
0.15	0.00
0.00	0.00
0.00	0.00
0.08	0.00
0.01	0.00
0.04	0.00
1.98	0.05
47.84	1.17
0.04	0.00
5.38	0.13
6.24	0.15
0.00	0.00
0.20	0.00
0.00	0.00
0.00	0.00
0.07	0.00
0.00	0.00
62.02	**1.52**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, PUGET SOUND NAVAL SHIPYARD

3

12 August 2004

(NOT Including Aluminum, Barium, and Zinc)

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.08	0.16	0.06	0.32	0.58	0.50	0.30	0.00	2.00
Arsenic	0.40	3.00	4.00	2.60	14.60	28.60	22.60	18.60	0.36	94.76
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.22	0.28	0.46	0.56	0.72	1.22	1.90	3.40	2.54	11.30
Chromium (+6)	0.00	0.00	0.08	0.12	0.16	0.56	1.32	1.14	1.91	5.29
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.22
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	12.90	26.50	51.90	64.10	84.50	202.90	318.90	278.90	389.52	1,430.12
Lead	0.02	0.08	0.14	0.08	0.32	0.66	0.78	0.66	0.58	3.32
Magnesium	18.30	55.10	65.10	41.10	195.10	425.10	373.10	315.10	20.00	1,508.00
Manganese	2.44	3.64	6.24	10.04	15.24	63.44	141.44	127.44	155.54	525.46
Molybdenum	0.00	0.00	0.24	0.00	0.22	0.42	0.48	0.50	3.80	5.66
Nickel	0.42	0.56	1.28	1.60	1.64	2.20	2.60	5.40	7.20	22.90
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.60
Strontium	0.30	1.10	1.50	1.10	4.70	8.30	7.90	6.10	1.60	32.60
Vanadium	0.00	0.00	0.20	0.00	0.30	0.46	0.46	0.38	0.00	1.80
Total Metal Wt.	35.00	90.34	131.30	121.36	317.82	734.44	871.98	758.74	583.05	3,644.03
Gravimetric Data	240	240	440	640	540	1,340	2,740	2,540	2,900	11,620
Ratio of Total Metal Analysis To Gravimetric Data	0.15	0.38	0.30	0.19	0.59	0.55	0.32	0.30	0.20	0.31

* All data are two times laboratory-reported value to account for cutting filters in half for lab. analysis.

** All data have been corrected by subtracting average PSNS 1st week blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - PSNS - 8/12 - Run 1

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	n/a
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	3,650
Flow Ratio (Duct/Probe):	1.506		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.05	N/A
2.35	N/A
0.00	N/A
0.00	N/A
0.28	N/A
0.13	N/A
0.01	N/A
0.00	N/A
35.39	N/A
0.08	N/A
37.32	N/A
13.00	N/A
0.14	N/A
0.57	N/A
0.00	N/A
0.01	N/A
0.81	N/A
0.04	N/A
90.19	**N/A**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, PUGET SOUND NAVAL SHIPYARD

4

13 August 2004
(NOT Including Aluminum, Barium, and Zinc)
Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Arsenic	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.62	1.22
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.32	0.00	0.00	0.00	0.22	0.00	0.26	0.40	0.50	1.70
Chromium (+6)	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.07	0.13	0.29
Cobalt	0.00	0.00	0.52	0.00	0.00	0.00	0.26	0.32	0.72	1.82
Copper	0.00	0.00	0.00	0.00	0.00	0.00	6.40	7.60	34.00	48.00
Iron	6.10	4.10	19.10	22.10	32.30	60.70	144.30	177.30	631.52	1,097.52
Lead	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.56	0.60
Magnesium	0.00	0.00	0.00	0.00	0.00	22.70	0.00	0.00	0.00	22.70
Manganese	0.56	0.58	1.14	1.84	3.24	7.64	18.64	19.44	89.54	142.62
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.00	0.00	0.60	0.22	0.32	0.00	0.32	0.48	1.00	2.94
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.30
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Metal Wt.	7.00	4.68	21.38	24.16	36.08	92.01	170.23	205.61	758.59	1,319.73
Gravimetric Data	240	340	340	340	340	240	740	840	1,600	5,020
Ratio of Total Metal Analysis To Gravimetric Data	0.03	0.01	0.06	0.07	0.11	0.38	0.23	0.24	0.47	0.26

* All data are two times laboratory-reported value to account for cutting filters in half for lab. analysis.
** All data have been corrected by subtracting average PSNS 1st week blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - PSNS - 8/13 - Run 1

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	16.7
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	2,431
Flow Ratio (Duct/Probe):	1,506		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.00	0.00
0.05	0.00
0.00	0.00
0.00	0.00
0.06	0.00
0.01	0.00
0.07	0.00
1.78	0.04
40.78	1.00
0.02	0.00
0.84	0.02
5.30	0.13
0.00	0.00
0.11	0.00
0.00	0.00
0.00	0.00
0.01	0.00
0.00	0.00
49.04	**1.20**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, PUGET SOUND NAVAL SHIPYARD

5

16 August 2004

(NOT Including Aluminum, Barium, and Zinc)

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	1.38	1.58	1.78	1.58	1.58	1.58	1.58	1.78	0.00	12.84
Arsenic	111.00	117.00	137.00	109.00	101.00	121.00	119.00	125.00	0.34	940.34
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.53	0.57	0.75	0.57	0.69	0.69	0.77	0.89	0.88	6.34
Chromium (+6)	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.06	0.21	0.32
Cobalt	0.00	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.28	0.54
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.40	7.40
Iron	99.60	107.00	134.40	109.60	123.80	150.80	178.80	224.80	432.00	1,560.80
Lead	1.45	1.65	1.85	1.45	1.45	1.65	1.65	1.85	0.00	13.00
Magnesium	1,406.00	1,426.00	1,726.00	1,376.00	1,262.00	1,526.00	1,486.00	1,526.00	0.00	11,734.00
Manganese	3.67	4.07	5.27	5.47	7.27	13.07	19.67	27.67	147.00	233.16
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.40	0.36	0.62	0.82	0.74	1.08	1.14	1.84	7.38	14.38
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	21.20	21.20	25.20	21.20	21.20	23.20	23.20	25.20	0.00	181.60
Vanadium	0.83	0.87	1.07	0.81	0.85	0.91	0.93	1.07	0.00	7.34
Total Metal Wt.	1,646.06	1,680.30	2,033.94	1,626.50	1,520.58	1,840.24	1,832.79	1,936.16	595.49	14,712.06
Gravimetric Data	40	40	240	340	340	440	540	540	1,200	3,720
Ratio of Total Metal Analysis To Gravimetric Data	41.15	42.01	8.47	4.78	4.47	4.18	3.39	3.59	0.50	3.95

* All data are two times laboratory-reported value to account for cutting filters in half for lab. analysis.

** All data have been corrected by subtracting average PSNS 2nd week blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - PSNS - 8/16 - Run 1

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	15.7
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	3,228
Flow Ratio (Duct/Probe):	1,506		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.36	0.01
26.32	0.68
0.00	0.00
0.00	0.00
0.18	0.00
0.01	0.00
0.02	0.00
0.21	0.01
43.68	1.14
0.36	0.01
328.38	8.54
6.52	0.17
0.00	0.00
0.40	0.01
0.00	0.00
0.00	0.00
5.08	0.13
0.21	0.01
411.72	**10.70**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, PUGET SOUND NAVAL SHIPYARD

6

17 August 2004
(NOT Including Aluminum, Barium, and Zinc)
Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	1.58	1.58	1.78	1.58	1.58	1.58	1.78	1.38	0.00	12.84
Arsenic	121.00	105.00	123.00	121.00	95.00	105.00	131.00	91.00	0.70	892.70
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.59	0.53	0.61	0.57	0.57	0.69	0.73	0.81	0.28	5.38
Chromium (+6)	0.00	0.00	0.00	0.00	0.00	0.04	0.05	0.08	0.15	0.32
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.28
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.80	5.80
Iron	116.60	105.60	121.60	113.20	112.80	137.00	170.80	172.80	352.00	1,402.40
Lead	1.65	1.45	1.65	1.45	1.45	1.45	1.85	1.45	0.00	12.40
Magnesium	1,506.00	1,292.00	1,546.00	1,506.00	1,166.00	1,248.00	1,646.00	1,084.00	0.00	10,994.00
Manganese	4.47	3.67	4.67	4.87	5.67	10.27	16.27	21.67	107.00	178.56
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.22	0.00	0.44
Nickel	0.42	0.30	0.44	0.56	0.92	0.80	1.04	1.60	6.78	12.86
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	23.20	21.20	23.20	21.20	21.20	21.20	23.20	19.20	0.00	173.60
Vanadium	0.95	0.85	0.97	0.85	0.81	0.85	1.03	0.75	0.00	7.06
Total Metal Wt.	1,776.46	1,532.18	1,823.92	1,771.28	1,406.00	1,527.10	1,993.75	1,394.96	472.99	13,698.64
Gravimetric Data	240	240	240	240	240	340	340	340	1,000	3,220
Ratio of Total Metal Analysis To Gravimetric Data	7.40	6.38	7.60	7.38	5.86	4.49	5.86	4.10	0.47	4.25

* All data are two times laboratory-reported value to account for cutting filters in half for lab. analysis.

** All data have been corrected by subtracting average PSNS 2nd week blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - PSNS - 8/17 - Run 1

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	15.7
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	2,699
Flow Ratio (Duct/Probe):	1,506		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.43	0.01
29.88	0.78
0.00	0.00
0.00	0.00
0.18	0.00
0.01	0.00
0.01	0.00
0.19	0.01
46.94	1.22
0.42	0.01
367.97	9.56
5.98	0.16
0.01	0.00
0.43	0.01
0.00	0.00
0.00	0.00
5.81	0.15
0.24	0.01
458.49	**11.92**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, PUGET SOUND NAVAL SHIPYARD

7

18 August 2004

(NOT Including Aluminum, Barium, and Zinc)

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	1.98	1.58	1.78	0.00	1.58	1.58	1.58	1.58	0.00	11.66
Arsenic	111.00	127.00	109.00	123.00	137.00	117.00	133.00	119.00	0.34	976.34
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.63	0.61	0.61	0.61	0.77	0.61	0.73	0.69	0.68	5.94
Chromium (+6)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.15
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.60	7.60
Iron	110.80	124.00	121.00	132.40	137.20	133.20	146.80	156.80	460.00	1,522.20
Lead	1.65	1.65	1.65	1.65	1.85	1.45	1.85	1.65	0.00	13.40
Magnesium	1,368.00	1,526.00	1,306.00	1,526.00	1,726.00	1,386.00	1,646.00	1,426.00	0.00	11,910.00
Manganese	4.27	67.67	5.47	5.87	6.67	8.87	10.87	15.67	147.00	272.36
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.76	0.80	0.72	0.72	1.00	0.96	0.76	1.12	7.38	14.22
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	23.20	23.20	23.20	23.20	25.20	21.20	25.20	21.20	0.00	185.60
Vanadium	0.93	0.97	0.91	0.97	2.43	2.49	3.31	0.87	0.00	12.88
Total Metal Wt.	1,623.22	1,873.48	1,570.34	1,814.42	2,039.70	1,673.36	1,970.10	1,744.58	623.15	14,932.35
Gravimetric Data	240	40	340	240	140	240	240	340	1,200	3,020
Ratio of Total Metal Analysis To Gravimetric Data	6.76	46.84	4.62	7.56	14.57	6.97	8.21	5.13	0.52	4.94

* All data are two times laboratory-reported value to account for cutting filters in half for lab. analysis.

** All data have been corrected by subtracting average PSNS 2nd week blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - PSNS - 8/18 - Run 1

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	17.3
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	2,402
Flow Ratio (Duct/Probe):	1,506		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.44	0.01
36.72	0.87
0.00	0.00
0.00	0.00
0.22	0.01
0.01	0.00
0.00	0.00
0.29	0.01
57.25	1.35
0.50	0.01
447.92	10.57
10.24	0.24
0.00	0.00
0.53	0.01
0.00	0.00
0.00	0.00
6.98	0.16
0.48	0.01
561.58	13.26

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, SOUTHWEST REGIONAL MAINTENANCE CENTER

15

7 October 04 - Run 2

(WITHOUT Aluminum, Barium, and Zinc)

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.52	0.52	0.72	0.80	1.04	2.80	9.20	17.60	59.23	92.43
Chromium (+6)	0.19	0.26	0.34	0.46	0.69	2.10	7.68	13.34	42.10	67.16
Cobalt	0.00	0.00	0.00	0.36	0.00	0.64	0.00	0.00	0.00	1.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	6.57	9.57	13.77	13.77	17.17	44.77	133.57	228.77	730.60	1,198.56
Lead	1.70	1.60	1.72	1.68	1.78	1.90	2.50	3.10	5.36	21.30
Magnesium	0.00	0.00	0.00	0.00	0.00	0.00	76.30	98.30	1.40	176.00
Manganese	1.24	1.48	2.06	2.66	3.86	11.66	35.66	71.66	219.26	349.54
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.48	1.90	2.70
Nickel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.36	0.60
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.00	0.00	0.00	0.00	0.01	0.36	0.50	0.00	0.87
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.46
Total Metal Wt.	10.21	13.42	18.61	19.73	24.54	63.88	265.58	433.98	1,060.67	1,910.62
Gravimetric Data	440	340	940	740	640	940	2,440	5,640	8,300	20,420
Ratio of Total Metal Analysis To Gravimetric Data	0.02	0.04	0.02	0.03	0.04	0.07	0.11	0.08	0.13	0.09

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - SIMA - 10/7-Run 2

Rod Diameter (inch):	0.125	Rod FeedRate(ft/min):	0.90
Rod Density (lb/cu.ft):	490	Weld Time (seconds):	4,178
Flow Ratio (Duct/Probe):	1,540		

Emissions/ Weld Time (mg/min)	Emissions/ Rod Used (mg/gm)
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
2.04	0.12
1.49	0.09
0.02	0.00
0.00	0.00
26.51	1.55
0.47	0.03
3.89	0.23
7.73	0.45
0.06	0.00
0.01	0.00
0.00	0.00
0.00	0.00
0.02	0.00
0.01	0.00
42.25	**2.48**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, SOUTHWEST REGIONAL MAINTENANCE CENTER

1

28 September 04 - Run 1

(WITHOUT Aluminum, Barium, and Zinc)

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.76	0.94	0.70	1.02	1.02	1.64	1.84	1.68	0.00	9.60
Arsenic	34.00	40.00	32.00	44.00	48.00	108.00	134.00	108.00	0.34	548.34
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.32	0.36	0.34	0.38	0.46	0.78	1.14	1.26	0.91	5.95
Chromium (+6)	0.00	0.00	0.00	0.00	0.00	0.14	0.38	0.66	1.18	2.36
Cobalt	0.22	0.46	2.00	0.00	0.00	1.80	0.50	0.82	0.00	5.80
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	48.97	59.17	60.77	69.77	88.77	210.77	414.77	500.77	512.60	1,966.36
Lead	0.60	0.70	0.60	0.76	0.92	1.68	2.50	2.50	1.36	11.58
Magnesium	308.30	392.30	280.30	436.30	526.30	1,260.30	1,620.30	1,274.30	29.00	6,127.40
Manganese	2.66	3.26	5.06	6.26	8.86	37.66	123.66	171.66	179.26	538.34
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.44
Nickel	0.00	0.22	0.22	0.00	0.00	0.26	0.22	0.26	0.28	1.46
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	10.82	12.22	10.62	13.02	15.02	23.02	29.02	23.02	1.90	138.62
Vanadium	0.38	0.44	0.36	0.48	54.00	0.92	1.18	0.94	0.00	58.70
Total Metal Wt.	407.02	510.06	392.96	571.98	743.34	1,646.96	2,329.50	2,085.86	727.27	9,414.95
Gravimetric Data	40	0	540	440	440	1,140	2,740	3,640	5,100	14,080
Ratio of Total Metal Analysis To Gravimetric Data	10.18	na	0.73	1.30	1.69	1.44	0.85	0.57	0.14	0.67

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - SIMA - 9/28 - Run 1

Rod Diameter (inch):	0.125	Rod FeedRate(ft/min):	0.56
Rod Density (lb/cu.ft):	490	Weld Time (seconds):	3,200
Flow Ratio (Duct/Probe):	1,540		

Emissions/ Weld Time (mg/min)	Emissions/ Rod Used (mg/gm)
0.28	0.03
15.83	1.48
0.00	0.00
0.00	0.00
0.17	0.02
0.07	0.01
0.17	0.02
0.00	0.00
56.78	5.32
0.33	0.03
176.93	16.58
15.54	1.46
0.01	0.00
0.04	0.00
0.00	0.00
0.00	0.00
4.00	0.38
1.69	0.16
271.86	**25.47**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, SOUTHWEST REGIONAL MAINTENANCE CENTER

2

28 September 04 - Run 2

(WITHOUT Aluminum, Barium, and Zinc)

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.28	0.00	0.00	0.00	0.22	0.42	0.74	0.86	1.07	3.59
Chromium (+6)	0.00	0.00	0.00	0.00	0.00	0.22	0.50	0.64	1.18	2.542
Cobalt	1.06	0.24	0.76	0.26	0.26	0.00	0.74	0.00	0.00	3.32
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	3.00
Iron	11.97	10.97	18.77	25.37	35.57	190.77	372.77	464.77	604.60	1,735.56
Lead	0.12	0.00	0.16	0.18	0.20	0.72	1.32	1.52	1.76	5.95
Magnesium	118.30	56.30	134.30	124.30	108.30	232.30	426.30	406.30	25.20	1,631.60
Manganese	1.56	2.26	3.66	5.86	8.86	67.66	149.66	183.66	199.26	622.44
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.36	0.58	1.34
Nickel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.34
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.46	0.18	0.50	0.48	0.42	0.98	1.82	1.82	2.70	9.32
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20
Total Metal Wt.	133.74	69.95	158.14	156.44	153.82	493.06	954.24	1,059.92	839.89	4,019.20
Gravimetric Data	240	0	140	240	240	1,640	3,540	4,140	5,100	15,280
Ratio of Total Metal Analysis To Gravimetric Data	0.56	na	1.13	0.65	0.64	0.30	0.27	0.26	0.16	0.26

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - SIMA - 9/28 - Run 2

Rod Diameter (inch):	0.125	Rod FeedRate(ft/min):	0.61
Rod Density (lb/cu.ft):	490	Weld Time (seconds):	3,479
Flow Ratio (Duct/Probe):	1,540		

Emissions/ Weld Time (mg/min)	Emissions/ Rod Used (mg/gm)
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.10	0.01
0.07	0.01
0.09	0.01
0.08	0.01
46.10	3.97
0.16	0.01
43.33	3.73
16.53	1.42
0.04	0.00
0.01	0.00
0.00	0.00
0.00	0.00
0.25	0.02
0.01	0.00
106.75	**9.20**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, SOUTHWEST REGIONAL MAINTENANCE CENTER

3

29 September 04 - Run1

(WITHOUT Aluminum, Barium, and Zinc)

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.00	0.00	0.00	0.00	0.22	0.46	0.70	0.84	0.71	2.93
Chromium (+6)	0.00	0.00	0.00	0.00	0.02	0.30	0.56	0.60	1.30	2.782
Cobalt	3.40	1.22	1.00	0.00	0.58	0.00	0.38	0.00	0.00	6.58
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.80	2.80
Iron	9.17	13.37	23.37	16.17	38.57	190.77	348.77	426.77	510.60	1,577.56
Lead	0.10	0.12	0.14	0.16	0.24	0.82	1.42	1.64	1.56	6.16
Magnesium	60.30	66.30	62.30	118.30	138.30	310.30	476.30	514.30	1.20	1,747.60
Manganese	1.86	2.86	5.46	3.46	10.26	77.66	147.66	173.66	175.26	598.14
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.34	0.48	1.12
Nickel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.38
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.26	0.28	0.24	0.48	0.56	1.22	2.02	2.22	0.30	7.54
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Metal Wt.	75.08	84.14	92.50	138.56	188.74	581.52	978.10	1,120.36	694.59	3,953.59
Gravimetric Data	340	40	440	540	540	1,940	3,940	4,140	5,900	17,820
Ratio of Total Metal Analysis To Gravimetric Data	0.22	2.10	0.21	0.26	0.35	0.30	0.25	0.27	0.12	0.22

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - SIMA - 9/29 - Run 1

Rod Diameter (inch):	0.125	Rod FeedRate(ft/min):	0.63
Rod Density (lb/cu.ft):	490	Weld Time (seconds):	3,605
Flow Ratio (Duct/Probe):	1,540		

Emissions/ Weld Time (mg/min)	Emissions/ Rod Used (mg/gm)
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.08	0.01
0.07	0.01
0.17	0.01
0.07	0.01
40.43	3.36
0.16	0.01
44.79	3.73
15.33	1.27
0.03	0.00
0.01	0.00
0.00	0.00
0.00	0.00
0.19	0.02
0.00	0.00
101.33	**8.43**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, SOUTHWEST REGIONAL MAINTENANCE CENTER

4

29 September 04 - Run 2

(WITHOUT Aluminum, Barium, and Zinc)

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.22	0.00	0.00	0.22	0.00	0.46	0.68	0.94	1.43	3.95
Chromium (+6)	0.00	0.00	0.00	0.00	0.00	0.20	0.36	0.60	1.42	2.582
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.34
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.20	3.20
Iron	7.49	10.17	16.97	25.17	31.37	194.77	320.77	482.77	726.60	1,816.08
Lead	0.14	0.14	0.16	0.24	0.20	0.80	1.22	1.76	2.18	6.80
Magnesium	200.30	172.30	190.30	240.30	188.30	344.30	506.30	628.30	31.20	2,501.60
Manganese	1.34	2.06	3.66	5.66	8.86	65.66	121.66	167.66	219.26	595.82
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.22	0.30	0.42	0.66	1.60
Nickel	0.00	0.00	0.00	0.28	0.00	0.00	0.20	0.24	0.44	1.16
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.50	0.50	0.60	0.78	0.42	1.22	1.62	2.42	2.90	10.92
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.26
Total Metal Wt.	209.98	185.16	211.68	272.64	229.14	607.62	953.10	1,285.10	989.89	4,944.31
Gravimetric Data	340	340	140	840	340	2,040	3,440	4,840	6,100	18,420
Ratio of Total Metal Analysis To Gravimetric Data	0.62	0.54	1.51	0.32	0.67	0.30	0.28	0.27	0.16	0.27

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - SIMA - 9/29 - Run 2

Rod Diameter (inch):	0.125	Rod FeedRate(ft/min):	0.63
Rod Density (lb/cu.ft):	490	Weld Time (seconds):	3,599
Flow Ratio (Duct/Probe):	1,540		

Emissions/ Weld Time (mg/min)	Emissions/ Rod Used (mg/gm)
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.10	0.01
0.07	0.01
0.01	0.00
0.08	0.01
46.63	3.88
0.17	0.01
64.23	5.35
15.30	1.27
0.04	0.00
0.03	0.00
0.00	0.00
0.00	0.00
0.28	0.02
0.01	0.00
126.94	**10.57**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, SOUTHWEST REGIONAL MAINTENANCE CENTER

5

30 September 04 - Run 1 (only run)
(WITHOUT Aluminum, Barium, and Zinc)
Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.31	0.51
Chromium (+6)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.096
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.42
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.40	32.00	36.40
Iron	6.67	7.93	15.17	19.57	29.37	45.97	73.97	130.37	752.60	1,081.62
Lead	0.14	0.16	0.14	0.14	0.18	0.14	0.18	0.16	0.34	1.54
Magnesium	150.30	134.30	178.30	192.30	242.30	184.30	214.30	144.30	10.40	1,450.80
Manganese	0.92	1.32	2.46	3.26	5.06	8.46	17.26	31.66	199.26	269.66
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.44
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.42	0.42	0.46	0.50	0.74	0.44	0.66	0.42	1.50	5.52
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Metal Wt.	158.44	144.34	196.52	215.76	277.84	239.30	306.36	311.30	997.15	2,847.01
Gravimetric Data	740	540	440	540	340	740	740	740	2,300	7,120
Ratio of Total Metal Analysis To Gravimetric Data	0.21	0.27	0.45	0.40	0.82	0.32	0.41	0.42	0.43	0.40

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - SIMA - 9/30 - Run 1

Wire Diameter (inch):	0.035	WireFeedRate(ft/min):	20.5
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	3,236
Flow Ratio (Duct/Probe):	1.540		

Emissions/ Weld Time (mg/min)	Emissions/Wire Used (mg/gm)
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.01	0.00
0.00	0.00
0.01	0.00
1.04	0.03
30.88	1.01
0.04	0.00
41.43	1.36
7.70	0.25
0.00	0.00
0.01	0.00
0.00	0.00
0.00	0.00
0.16	0.01
0.00	0.00
81.29	**2.67**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, SOUTHWEST REGIONAL MAINTENANCE CENTER

6

1 October 04 - Run 1

(WITHOUT Aluminum, Barium, and Zinc)

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.35
Chromium (+6)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.064
Cobalt	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.00	13.00
Iron	5.17	20.57	4.77	7.73	0.00	18.37	35.17	69.57	272.60	433.95
Lead	0.12	0.14	0.00	0.10	0.12	0.18	0.18	0.12	0.05	0.98
Magnesium	80.30	198.30	72.30	86.30	90.30	162.30	152.30	70.30	0.80	913.20
Manganese	0.54	0.72	0.98	1.38	2.06	4.26	9.46	19.06	95.26	133.72
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.32	0.54	0.30	0.36	0.36	0.46	0.40	0.26	0.10	3.06
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Metal Wt.	86.94	220.26	78.35	95.86	92.83	185.56	197.50	159.30	381.95	1,498.54
Gravimetric Data	440	440	340	0	340	340	240	640	1,000	3,780
Ratio of Total Metal Analysis To Gravimetric Data	0.20	0.50	0.23	na	0.27	0.55	0.82	0.25	0.38	0.40

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - SIMA - 10/1 - Run 1

Wire Diameter (inch):	0.035	WireFeedRate(ft/min):	20.3
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	1,745
Flow Ratio (Duct/Probe):	1,540		

Emissions/ Weld Time (mg/min)	Emissions/Wire Used (mg/gm)
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.02	0.00
0.00	0.00
0.01	0.00
0.69	0.02
22.98	0.76
0.05	0.00
48.36	1.61
7.08	0.24
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.16	0.01
0.00	0.00
79.35	**2.64**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, SOUTHWEST REGIONAL MAINTENANCE CENTER

7

1 October 04 - Run 2

(WITHOUT Aluminum, Barium, and Zinc)

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.24	0.00	0.26	0.40	0.48	0.70	1.14	2.20	10.23	15.65
Chromium (+6)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.76	0.768
Cobalt	0.00	0.00	0.00	0.46	0.44	0.00	0.00	0.00	0.38	1.28
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.20	18.00	21.20
Iron	6.01	8.33	12.77	18.57	19.37	32.77	53.17	129.97	500.60	781.56
Lead	0.14	0.12	0.14	0.16	0.12	0.16	0.20	0.24	1.08	2.32
Magnesium	212.30	148.30	184.30	220.30	92.30	216.30	180.30	66.30	0.00	1,320.40
Manganese	0.32	0.54	0.86	1.18	1.54	2.46	4.46	8.86	41.26	61.48
Molybdenum	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.88
Nickel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.62
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.44	0.42	0.50	0.62	0.34	0.44	0.44	0.26	0.00	3.42
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Metal Wt.	219.70	157.70	198.82	241.68	114.58	252.82	239.70	211.03	573.55	2,209.58
Gravimetric Data	140	140	540	440	540	440	440	540	1,500	4,720
Ratio of Total Metal Analysis To Gravimetric Data	1.57	1.13	0.37	0.55	0.21	0.57	0.54	0.39	0.38	0.47

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - SIMA - 10/1 - Run 2

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	15.2
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	2,754
Flow Ratio (Duct/Probe):	1,540		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.53	0.01
0.03	0.00
0.04	0.00
0.71	0.02
26.22	0.70
0.08	0.00
44.30	1.19
2.06	0.06
0.03	0.00
0.02	0.00
0.00	0.00
0.00	0.00
0.11	0.00
0.00	0.00
74.13	**1.99**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, SOUTHWEST REGIONAL MAINTENANCE CENTER

8

4 October 04 - Run 1

(WITHOUT Aluminum, Barium, and Zinc)

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.58	0.58
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.30	0.38	0.72	1.08	1.28	1.50	1.96	3.20	21.23	31.65
Chromium (+6)	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	1.20	1.256
Cobalt	0.58	0.00	0.56	0.00	0.00	0.00	0.00	0.00	0.42	1.56
Copper	0.00	0.00	0.00	0.00	0.00	2.80	4.20	6.40	66.00	79.40
Iron	9.77	18.57	54.37	104.17	90.77	95.97	99.97	158.57	1,104.60	1,736.76
Lead	1.70	1.56	1.62	1.90	1.88	1.76	1.76	1.78	3.76	17.68
Magnesium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Manganese	0.44	0.82	1.86	2.66	3.06	4.06	6.26	10.46	81.26	110.88
Molybdenum	0.00	0.20	0.48	0.62	0.68	0.70	0.66	0.74	8.40	12.48
Nickel	0.00	0.00	0.26	0.32	0.36	0.22	0.00	0.00	1.12	2.28
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Metal Wt.	12.79	21.53	59.87	110.75	98.03	107.01	114.82	181.20	1,288.57	1,994.53
Gravimetric Data	40	340	740	440	640	540	140	640	2,100	5,620
Ratio of Total Metal Analysis To Gravimetric Data	0.32	0.06	0.08	0.25	0.15	0.20	0.82	0.28	0.61	0.35

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - SIMA - 10/4 - Run 1

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	14.7
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	3,139
Flow Ratio (Duct/Probe):	1,540		

Emissions/ Weld Time (mg/min)	Emissions/Wire Used (mg/gm)
0.00	0.00
0.02	0.00
0.00	0.00
0.00	0.00
0.93	0.03
0.04	0.00
0.05	0.00
2.34	0.06
51.12	1.41
0.52	0.01
0.00	0.00
3.26	0.09
0.37	0.01
0.07	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
58.71	**1.62**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, SOUTHWEST REGIONAL MAINTENANCE CENTER

9

4 October 04 - Run 2

(WITHOUT Aluminum, Barium, and Zinc)

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.28	0.32	0.44	0.52	0.64	1.00	1.32	2.40	16.03	22.95
Chromium (+6)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.64	0.636
Cobalt	0.40	0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.36	1.04
Copper	2.80	0.00	0.00	0.00	0.00	0.00	0.00	4.20	34.00	41.00
Iron	8.97	23.57	20.37	24.17	30.77	50.57	62.57	114.37	844.60	1,179.96
Lead	1.66	1.78	1.68	1.86	1.70	1.56	1.76	1.72	2.76	16.44
Magnesium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Manganese	0.36	0.56	1.08	1.22	1.56	3.26	5.06	10.86	109.26	133.22
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.68
Nickel	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.80
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Metal Wt.	14.77	26.23	23.57	27.77	34.67	56.39	70.99	133.55	1,008.83	1,396.73
Gravimetric Data	0	240	340	540	140	440	540	740	1,820	4,800
Ratio of Total Metal Analysis To Gravimetric Data	na	0.11	0.07	0.05	0.25	0.13	0.13	0.18	0.55	0.29

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - SIMA - 10/4 - Run 2

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	13.7
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	3,336
Flow Ratio (Duct/Probe):	1,540		

Emissions/ Weld Time (mg/min)	Emissions/Wire Used (mg/gm)
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.64	0.02
0.02	0.00
0.03	0.00
1.14	0.03
32.68	0.97
0.46	0.01
0.00	0.00
3.69	0.11
0.02	0.00
0.02	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
38.69	**1.15**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, SOUTHWEST REGIONAL MAINTENANCE CENTER

10

5 October 04 - Run 1

(WITHOUT Aluminum, Barium, and Zinc)

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.30	0.60	0.66	0.64	0.88	1.26	2.00	3.60	27.23	37.17
Chromium (+6)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.64	0.652
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	3.40	5.80	48.00	57.20
Iron	7.61	20.17	35.37	30.77	43.97	60.97	98.37	180.37	1,344.60	1,822.20
Lead	0.14	0.18	0.18	0.14	0.20	0.22	0.28	0.36	2.36	4.02
Magnesium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Manganese	0.32	1.00	1.86	1.66	2.46	4.06	7.66	13.86	127.26	160.14
Molybdenum	0.00	0.00	0.20	0.00	0.00	0.20	0.00	0.00	1.70	2.10
Nickel	0.00	0.30	0.20	0.22	0.24	0.00	0.00	0.22	0.82	2.00
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Metal Wt.	8.37	22.25	38.47	33.43	47.75	66.71	111.71	204.22	1,552.81	2,085.68
Gravimetric Data	340	140	240	270	440	340	540	740	2,200	5,250
Ratio of Total Metal Analysis To Gravimetric Data	0.02	0.16	0.16	0.12	0.11	0.20	0.21	0.28	0.71	0.40

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - SIMA - 10/5 - Run 1

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	13.7
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	2,926
Flow Ratio (Duct/Probe):	1,540		

Emissions/ Weld Time (mg/min)	Emissions/ Wire Used (mg/gm)
0.00	0.00
0.01	0.00
0.00	0.00
0.00	0.00
1.17	0.03
0.02	0.00
0.00	0.00
1.81	0.05
57.54	1.71
0.13	0.00
0.00	0.00
5.06	0.15
0.07	0.00
0.06	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
65.86	**1.96**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, SOUTHWEST REGIONAL MAINTENANCE CENTER

11

5 October 04 - Run 2

(WITHOUT Aluminum, Barium, and Zinc)

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.28	0.38	0.50	0.58	0.78	1.10	1.82	3.20	23.23	31.87
Chromium (+6)	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.74	0.762
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.32
Copper	0.00	0.00	0.00	0.00	0.00	0.00	2.80	5.00	40.00	47.80
Iron	8.97	13.97	21.97	25.37	31.37	48.37	83.17	158.37	1,152.60	1,544.16
Lead	0.16	0.18	0.16	0.16	0.20	0.22	0.22	0.26	1.36	2.88
Magnesium	0.00	0.00	0.00	0.00	14.30	12.30	0.00	0.00	0.00	26.60
Manganese	0.34	0.62	1.42	1.66	2.26	3.86	7.26	13.86	135.26	166.54
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.28
Nickel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.84	0.84
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.05	0.00	0.00	0.05	0.05	0.00	0.00	0.00	0.17
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Metal Wt.	9.75	15.20	24.05	27.77	48.96	65.90	95.27	180.71	1,354.63	1,822.22
Gravimetric Data	540	240	340	540	840	840	540	940	2,000	6,820
Ratio of Total Metal Analysis To Gravimetric Data	0.02	0.06	0.07	0.05	0.06	0.08	0.18	0.19	0.68	0.27

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals -SIMA - 10/5 - Run 2

Wire Diameter (inch):	0.045	WireFeedRate(ft/min):	13.7
Wire Density (lb/cu.ft):	490	Weld Time (seconds):	3,285
Flow Ratio (Duct/Probe):	1,540		

Emissions/ Weld Time (mg/min)	Emissions/Wire Used (mg/gm)
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.90	0.03
0.02	0.00
0.01	0.00
1.34	0.04
43.43	1.29
0.08	0.00
0.75	0.02
4.68	0.14
0.01	0.00
0.02	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
51.26	**1.53**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, SOUTHWEST REGIONAL MAINTENANCE CENTER

12

6 October 04 - Run 1
(WITHOUT Aluminum, Barium, and Zinc)
Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.26
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.46	0.56	0.74	0.78	1.12	2.40	9.20	19.80	43.23	78.29
Chromium (+6)	0.09	0.11	0.21	0.35	0.56	1.96	7.76	15.76	43.10	69.896
Cobalt	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.24	0.00	0.56
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	3.00
Iron	10.17	15.57	21.77	19.97	26.37	43.97	127.37	276.77	604.60	1,146.56
Lead	0.16	0.16	0.18	1.60	1.82	1.86	2.50	3.30	4.76	16.30
Magnesium	0.00	0.00	0.00	0.00	0.00	0.00	40.30	78.30	0.00	118.60
Manganese	0.94	1.44	2.06	2.46	4.26	10.26	35.66	101.66	219.26	378.00
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.22	0.36	0.58	3.80	4.96
Nickel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.36
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.42	0.00	0.63
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.38
Total Metal Wt.	11.82	17.83	24.96	25.47	34.13	60.67	223.36	496.82	922.75	1,817.80
Gravimetric Data	140	440	140	340	440	740	1,940	4,940	6,700	15,820
Ratio of Total Metal Analysis To Gravimetric Data	0.08	0.04	0.18	0.07	0.08	0.08	0.12	0.10	0.14	0.11

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - SIMA - 10/6 - Run 1

Rod Diameter (inch):	0.125	Rod FeedRate(ft/min):	0.85
Rod Density (lb/cu.ft):	490	Weld Time (seconds):	2,959
Flow Ratio (Duct/Probe):	1,540		

Emissions/ Weld Time (mg/min)	Emissions/ Rod Used (mg/gm)
0.00	0.00
0.01	0.00
0.00	0.00
0.00	0.00
2.44	0.15
2.18	0.14
0.02	0.00
0.09	0.01
35.80	2.22
0.51	0.03
3.70	0.23
11.80	0.73
0.15	0.01
0.01	0.00
0.00	0.00
0.00	0.00
0.02	0.00
0.01	0.00
56.76	**3.52**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, SOUTHWEST REGIONAL MAINTENANCE CENTER

13

6 October 04 - Run 2

(WITHOUT Aluminum, Barium, and Zinc)

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.46	0.58	1.02	0.82	1.12	3.40	11.80	24.00	35.23	78.43
Chromium (+6)	0.15	0.18	0.29	0.38	0.73	2.82	10.74	16.94	34.70	66.926
Cobalt	0.38	0.48	1.50	0.32	0.00	0.00	0.00	0.74	1.30	4.72
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	16.37	14.77	47.37	18.57	24.97	54.77	165.37	330.77	516.60	1,189.56
Lead	1.76	1.90	1.90	1.84	1.84	0.50	1.28	2.10	4.36	17.44
Magnesium	0.00	0.00	18.30	14.30	12.30	44.30	150.30	176.30	11.80	427.60
Manganese	0.88	1.26	2.26	2.46	4.06	13.66	43.66	9.26	153.26	230.76
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.68	1.74	2.80
Nickel	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.66	0.42	1.28
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.01	0.10	0.08	0.18	0.20	0.66	0.84	0.10	2.15
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.34	0.56
Total Metal Wt.	19.99	19.18	72.73	38.76	45.19	119.84	384.18	562.50	759.85	2,022.22
Gravimetric Data	540	40	140	540	440	940	2,540	5,440	4,800	15,420
Ratio of Total Metal Analysis To Gravimetric Data	0.04	0.48	0.52	0.07	0.10	0.13	0.15	0.10	0.16	0.13

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - SIMA - 10/6 - Run 2

Rod Diameter (inch):	0.125	Rod FeedRate(ft/min):	0.85
Rod Density (lb/cu.ft):	490	Weld Time (seconds):	2,959
Flow Ratio (Duct/Probe):	1,540		

Emissions/ Weld Time (mg/min)	Emissions/ Rod Used (mg/gm)
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
2.45	0.15
2.09	0.13
0.15	0.01
0.00	0.00
37.15	2.31
0.54	0.03
13.35	0.83
7.21	0.45
0.09	0.01
0.04	0.00
0.00	0.00
0.00	0.00
0.07	0.00
0.02	0.00
63.15	**3.92**

METAL ANALYSIS (Micrograms), CASCADE IMPACTOR, SOUTHWEST REGIONAL MAINTENANCE CENTER

14

7 October 04 - Run 1

(WITHOUT Aluminum, Barium, and Zinc)

Cascade Impactor Stage

	1	2	3	4	5	6	7	8	9	Total of All Stages
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.24
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.44	0.48	0.64	0.74	1.00	2.40	7.60	17.40	49.23	79.93
Chromium (+6)	0.11	0.13	0.23	0.34	0.57	2.00	6.30	16.74	46.90	73.33
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	7.33	12.77	17.57	15.97	20.77	39.97	108.57	220.77	728.60	1,172.32
Lead	1.76	1.78	1.78	1.86	0.28	0.44	0.94	3.30	5.36	17.46
Magnesium	26.30	32.30	46.30	26.30	68.30	50.30	168.30	178.30	20.40	616.80
Manganese	0.84	1.02	19.66	2.26	3.46	9.86	27.66	71.66	219.26	355.68
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.52	2.40	3.24
Nickel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.50	0.88
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.14	0.16	0.20	0.10	0.26	0.20	0.68	0.78	0.50	2.98
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.46
Total Metal Wt.	36.91	48.63	86.37	47.56	94.63	105.16	320.36	509.84	1,073.85	2,323.32
Gravimetric Data	40	40	440	40	840	740	1,740	4,340	8,400	16,620
Ratio of Total Metal Analysis To Gravimetric Data	0.92	1.22	0.20	1.19	0.11	0.14	0.18	0.12	0.13	0.14

* All data are two times laboratory-reported value to account for cutting filters in half for lab. Analysis.

** All data have been corrected by subtracting average blank values. All negative values have been changed to zero.

Relative Emissions of Total Metals - SIMA - 10/7-Run 1

Rod Diameter (inch):	0.125	Rod FeedRate(ft/min):	0.85
Rod Density (lb/cu.ft):	490	Weld Time (seconds):	3,290
Flow Ratio (Duct/Probe):	1,540		

Emissions/ Weld Time (mg/min)	Emissions/ Rod Used (mg/gm)
0.00	0.00
0.01	0.00
0.00	0.00
0.00	0.00
2.24	0.14
2.06	0.13
0.00	0.00
0.00	0.00
32.92	2.04
0.49	0.03
17.32	1.08
9.99	0.62
0.09	0.01
0.02	0.00
0.00	0.00
0.00	0.00
0.08	0.01
0.01	0.00
65.25	**4.05**

Appendix I
Summary of Industrial Hygiene Data Metal Content

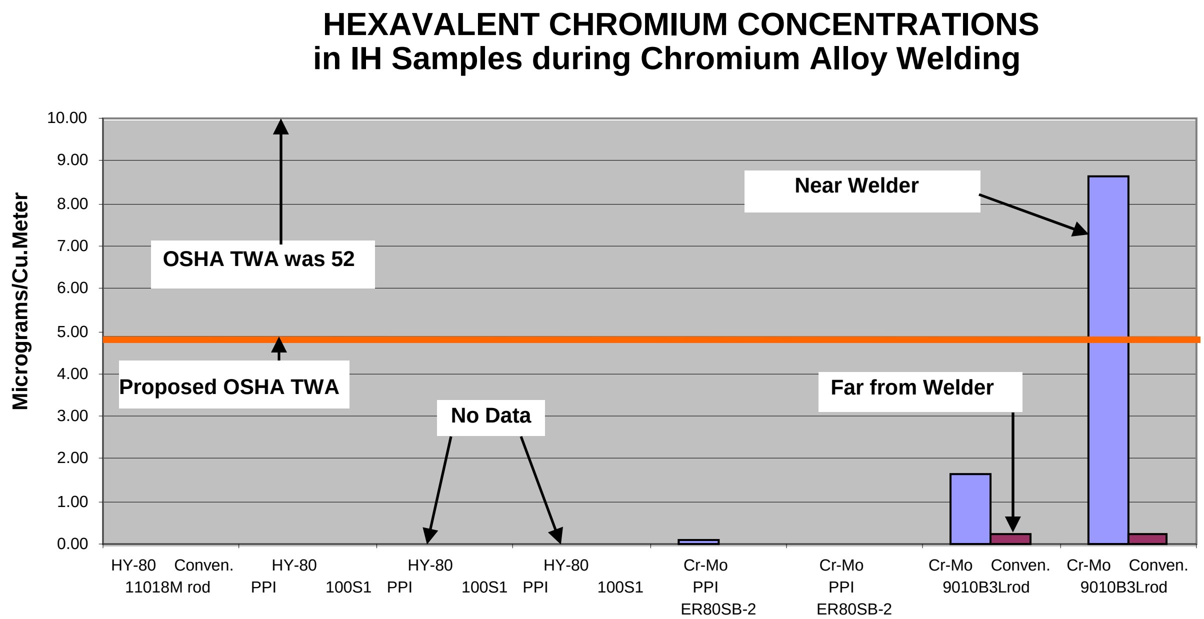


FIGURE I-1: Hexavalent Chromium Concentrations

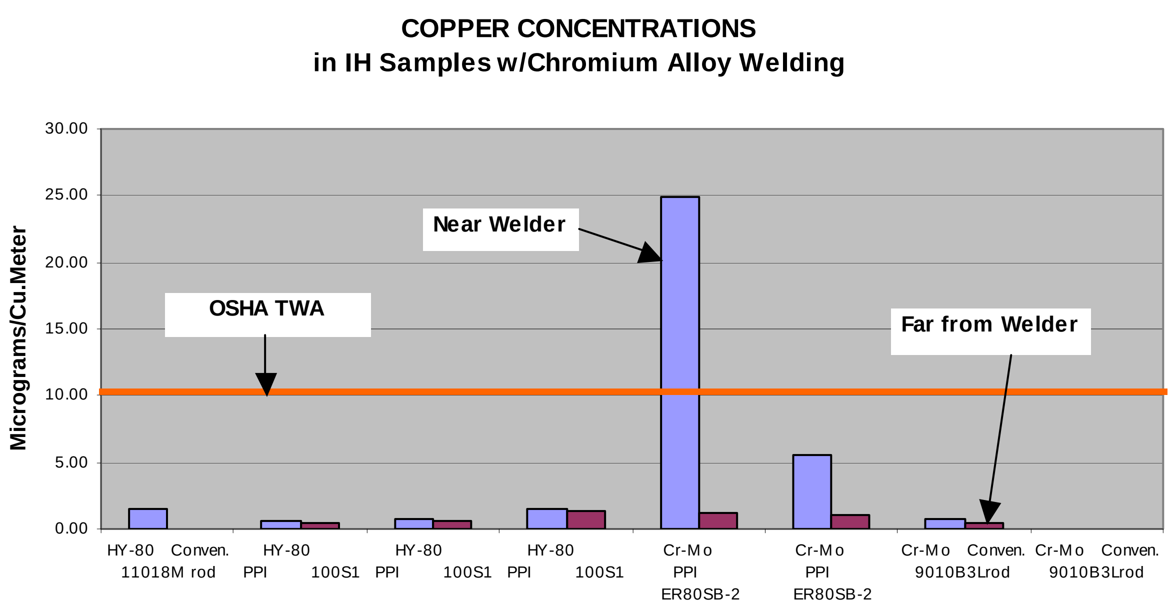


FIGURE I-2: Copper Concentrations

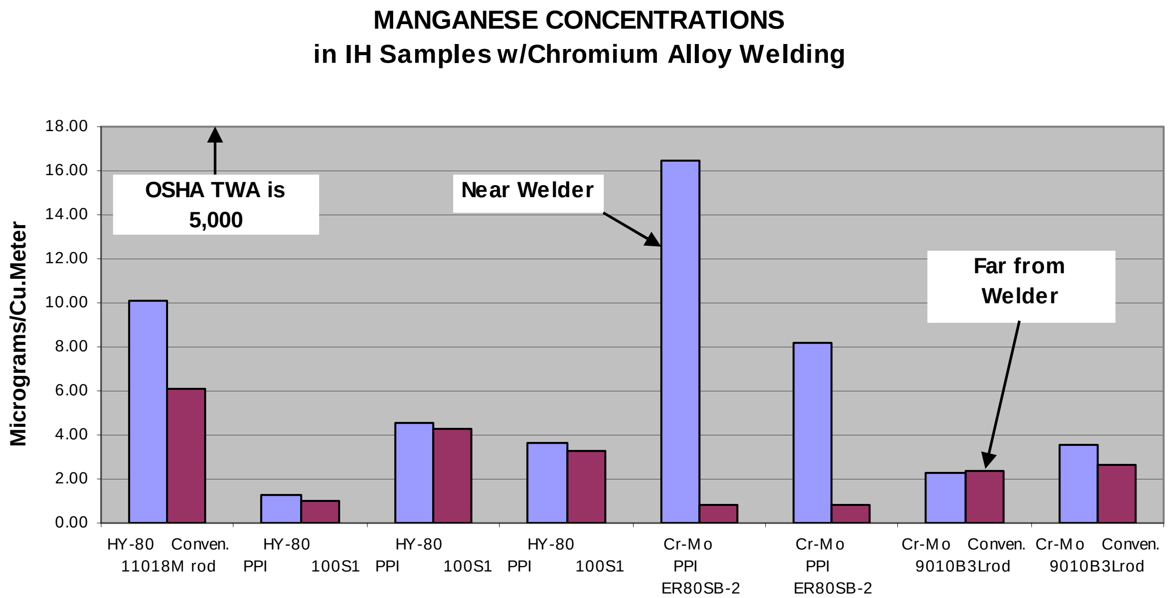


FIGURE I-3: Manganese Concentrations

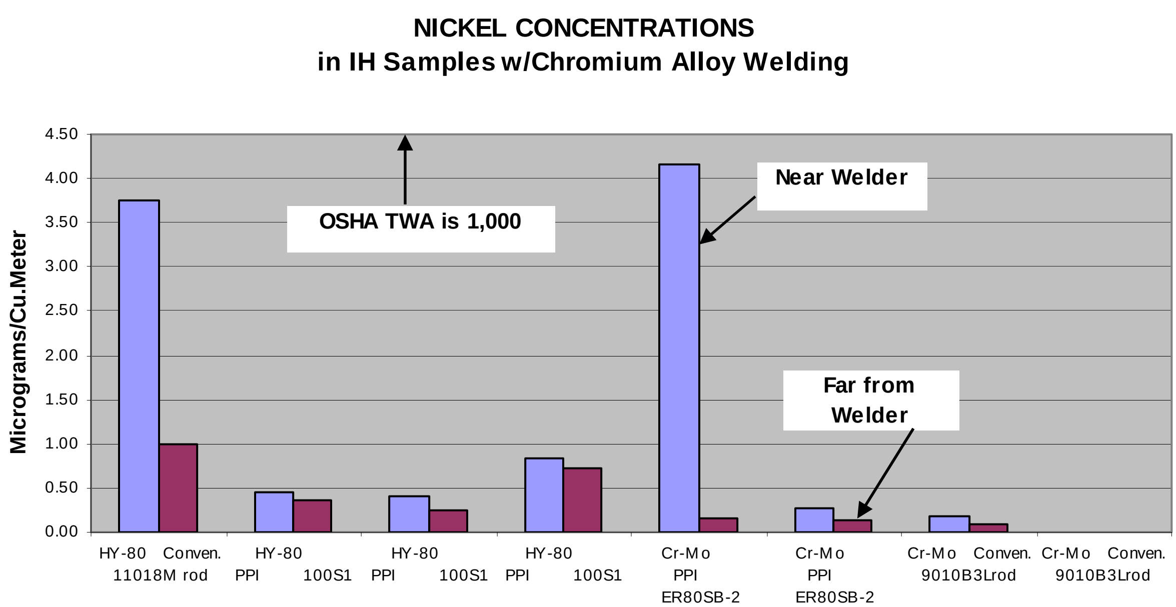


FIGURE I-4: Nickel Concentrations

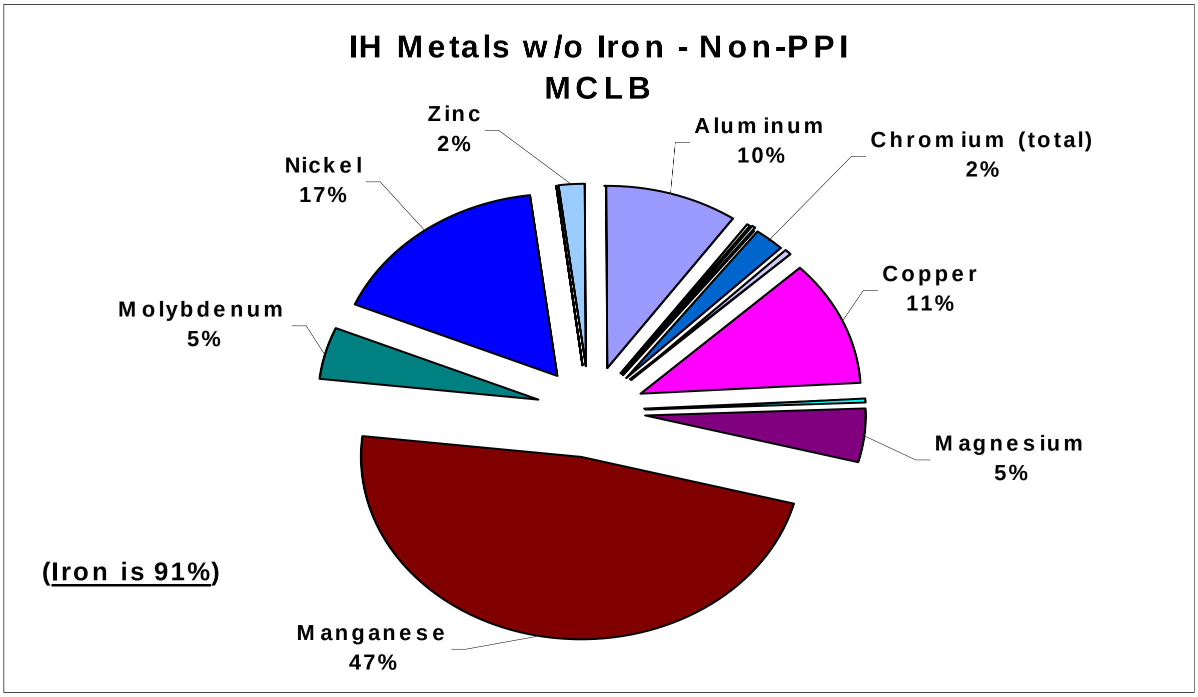


FIGURE I-5: IH Metals without Iron – Non-PPI- MCLB

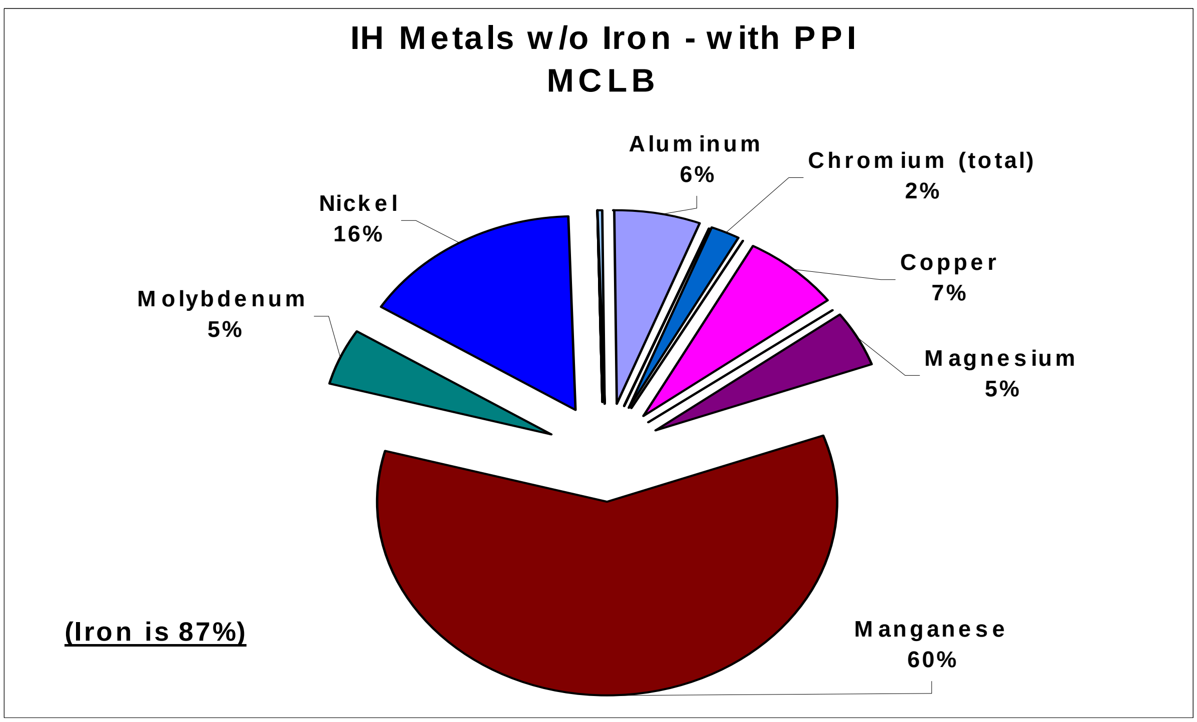


FIGURE I-6: IH Metals without Iron – PPI- MCLB

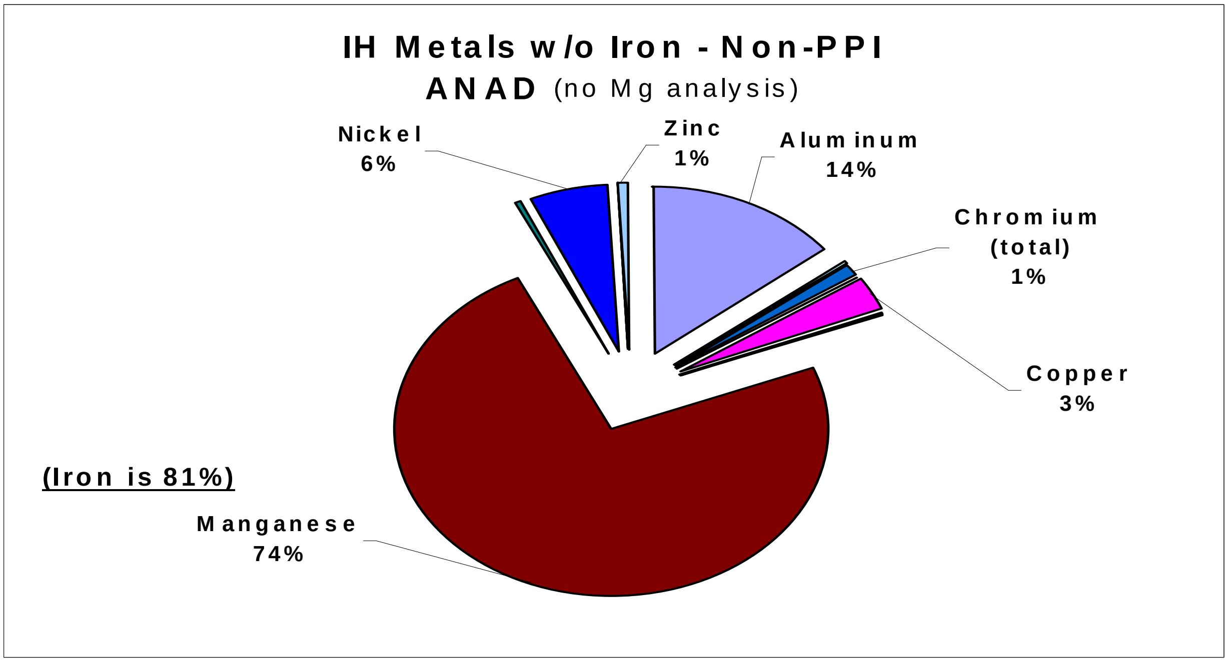


FIGURE I-7: IH Metals without Iron – Non-PPI- ANAD

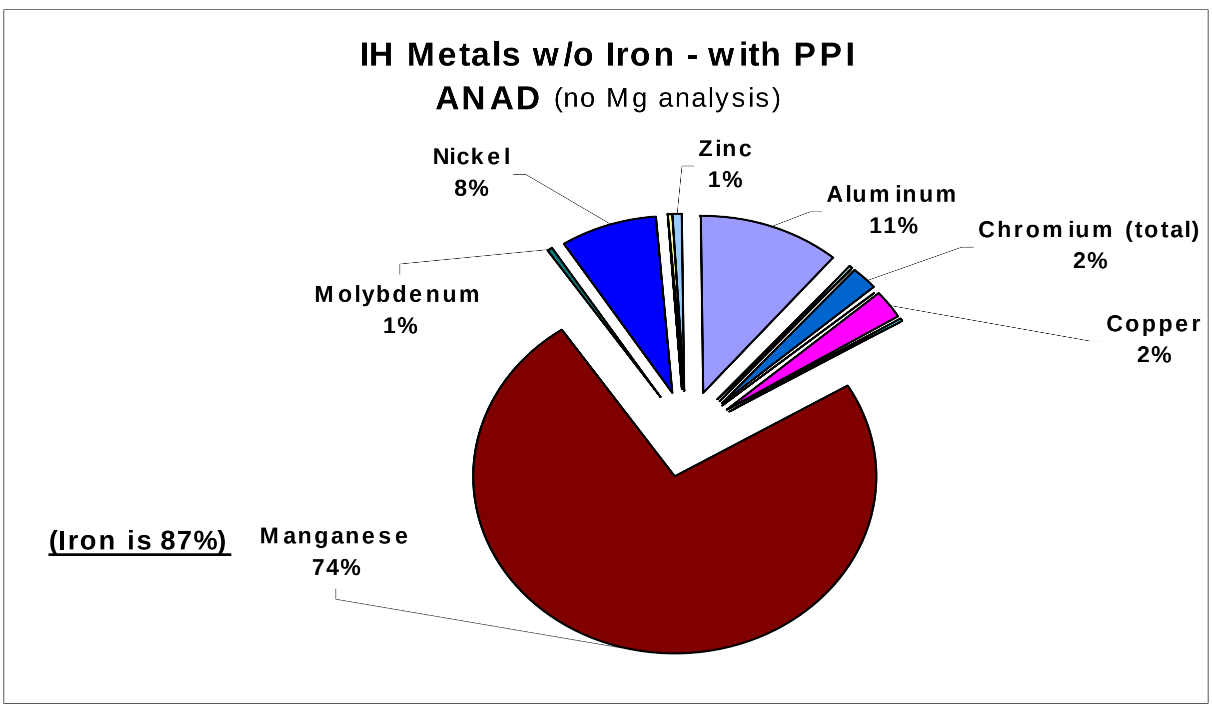


FIGURE I-8: IH Metals without Iron – PPI- ANAD

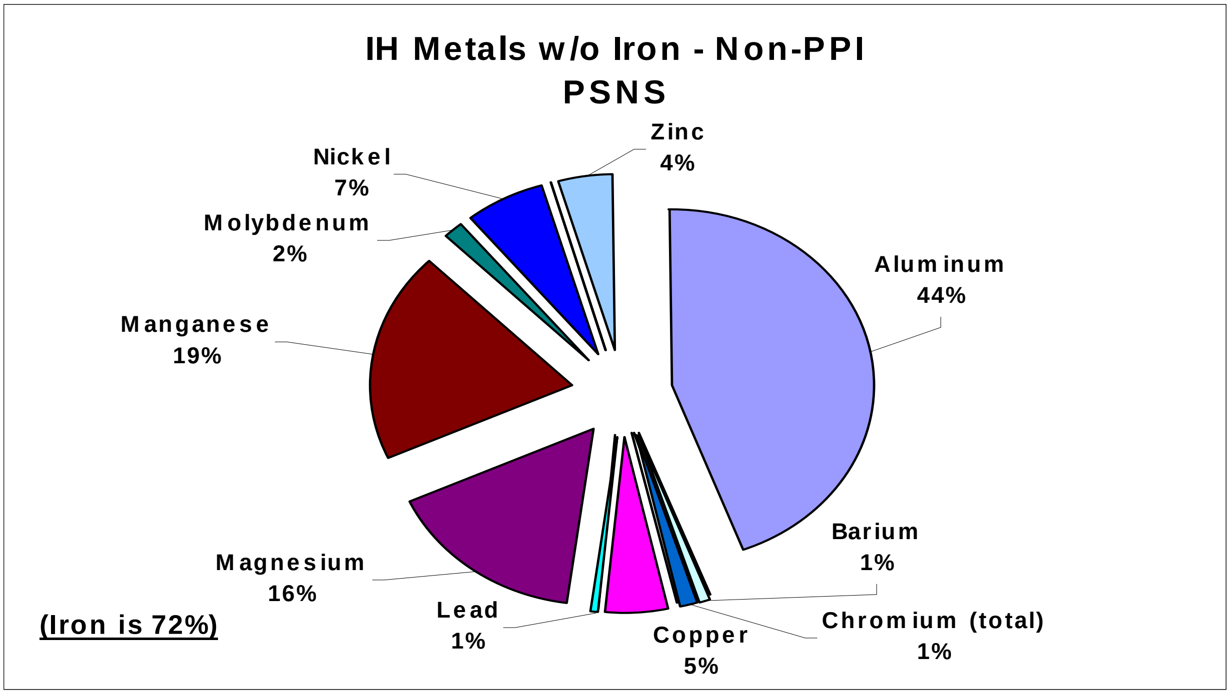


FIGURE I-9: IH Metals without Iron – Non-PPI- PSNS

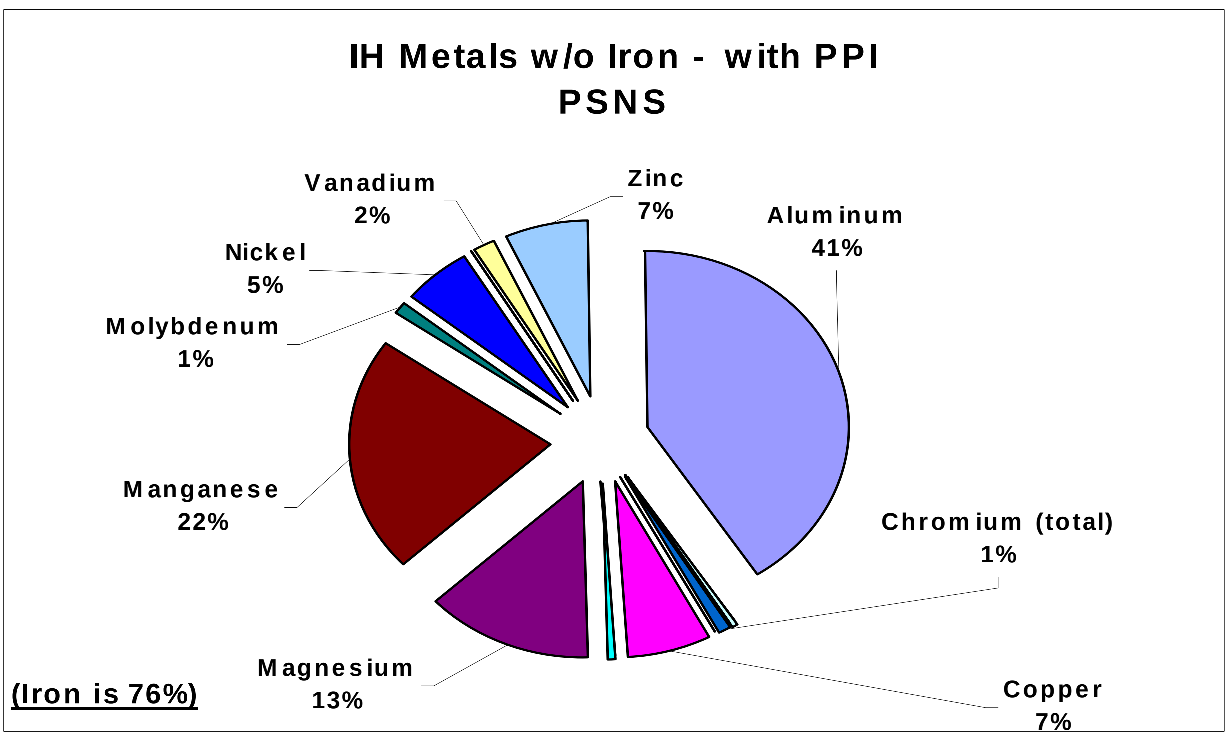


FIGURE I-10: IH Metals without Iron – PPI- PSNS

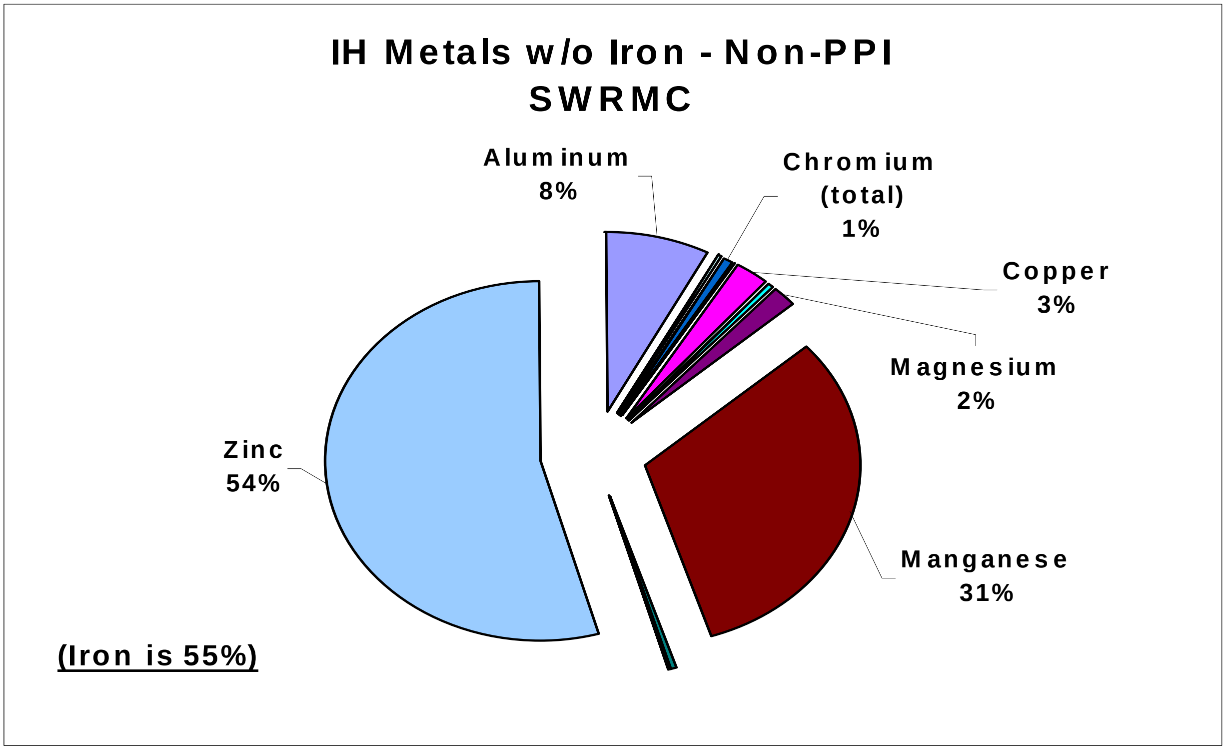


FIGURE I-11: IH Metals without Iron – Non-PPI- SWRMC

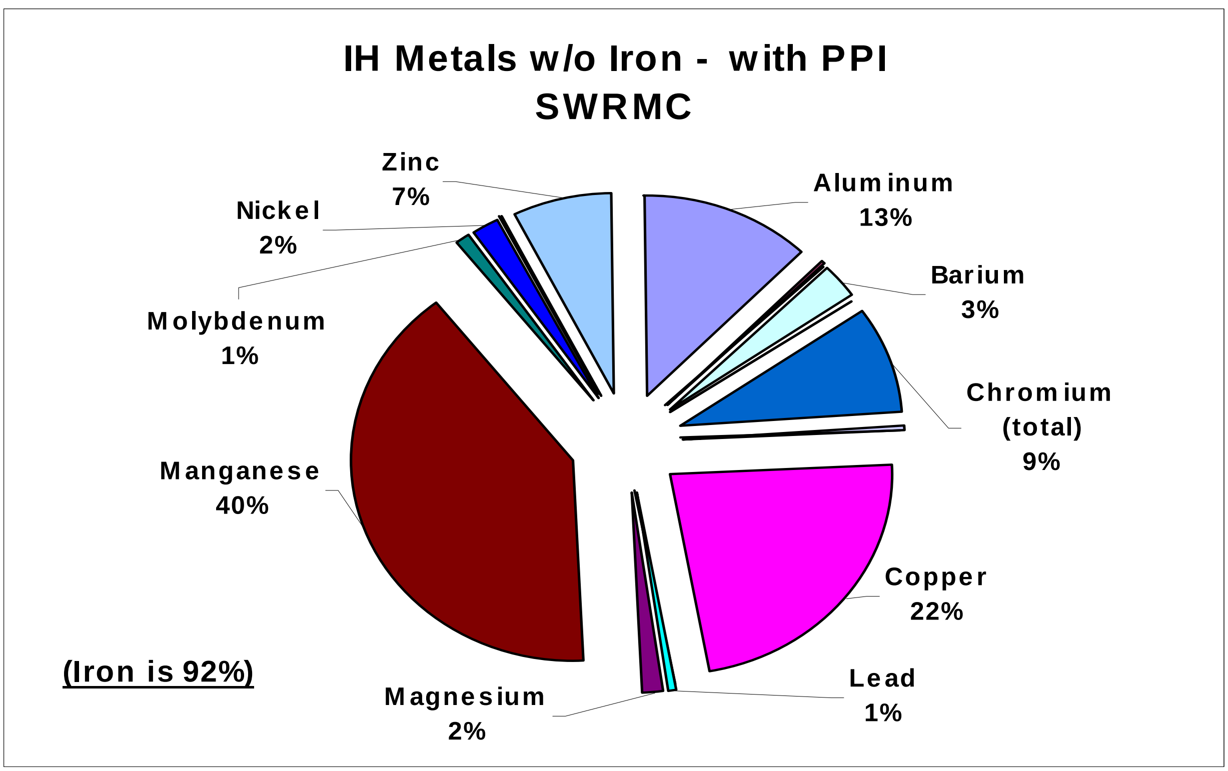


FIGURE I-12: IH Metals without Iron – PPI- SWRMC

Southwest Regional Maintenance Center (SWRMC), San Diego, CA - Industrial Hygiene Metal Data (microgram/cu.meter)
Corrected for Blank Values

METAL	Samples Taken Near Welder (about 2 feet)					Samples taken Away From Welder (about 10 feet)					Blank Values (microgram)		
	4-Oct	5-Oct	6-Oct	7-Oct	Aver. Near Welder	4-Oct	5-Oct	6-Oct	7-Oct	Average Away	wk1	wk2	Avg.
Aluminum	16.61	0.00	0.00	0.00	4.15	1.19	1.02	0.00	0.00	0.55	0	0	0
Antimony	0.22	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0	0	0
Arsenic	0.49	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0	0	0
Barium	0.26	0.09	0.15	0.00	0.12	0.00	0.11	0.00	0.00	0.03	0	0	0
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0
Chromium (total)	12.76	2.37	0.78	1.01	4.23	0.37	0.24	0.62	0.73	0.49	0.21	0.29	0.25
Chromium (+6)	0.07	0.02	1.63	8.63	2.59	0.00	-0.02	0.24	0.23	0.11	0.049	0.045	0.047
Cobalt	0.25	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0	0	0
Copper	24.94	5.61	0.75	0.00	7.82	1.20	1.09	0.48	0.00	0.69	0	0	0
Iron	1619.72	143.23	46.70	15.70	456.34	38.90	21.91	17.62	11.11	22.38	0	0	0
Lead	0.21	0.13	0.00	0.10	0.11	0.00	0.00	0.07	0.08	0.04	0	0	0
Magnesium	2.49	0.00	0.00	0.00	0.62	0.00	0.00	0.00	0.00	0.00	0	0	0
Manganese	16.43	8.20	2.29	3.51	7.61	0.79	0.84	2.37	2.62	1.66	0	0	0
Molybdenum	0.08	0.68	0.60	0.11	0.37	0.30	0.11	0.11	0.00	0.13	0	0	0
Nickel	4.17	0.27	0.18	0.00	1.15	0.15	0.13	0.09	0.00	0.09	0	0	0
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0
Strontium	0.06	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0	0	0
Vanadium	0.06	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0	0	0
Zinc	1.96	0.82	0.31	0.36	0.86	0.32	0.27	0.30	0.13	0.26	0.98	0.719	0.8495
TOTAL METALS	**1700.8**	**161.4**	**53.4**	**29.4**	**486.3**	**43.2**	**25.7**	**21.9**	**14.9**	**26.4**			

MCLB, ALBANY, GA - Industrial Hygiene Metal Data (microgram/cu.meter)
Corrected for Blank Values

METAL	Samples Taken Near Welder (about 2 feet)				Samples taken Away From Welder (about 10 feet)				Blank Values (microgram)
	16-Sep	17-Sep	18-Sep	Aver. Near Welder	16-Sep	17-Sep	18-Sep	Average Away	
Aluminum	0.14	0.00	1.56	0.57	0.00	0.56	0.72	0.42	3.36
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Arsenic	0.02	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0
Barium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Chromium (total)	0.14	0.000	0.43	0.19	0.17	0.02	0.16	0.12	0.3
Chromium (+6)	0.00	0.007	0.002	0.00	0.000	0.000	0.005	0.00	0.022
Cobalt	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0
Copper	5.74	0.26	1.23	2.41	0.25	0.00	0.88	0.38	0
Iron	72.96	24.12	110.49	69.19	28.14	8.63	48.95	28.57	2.83
Lead	0.03	0.02	0.02	0.02	0.01	0.00	0.00	0.00	0
Manganese	11.97	5.78	4.77	7.51	3.69	1.64	2.40	2.58	0.0358
Molybdenum	0.26	0.05	0.48	0.26	0.17	0.04	0.28	0.16	0
Nickel	1.39	0.31	1.84	1.18	0.61	0.12	0.91	0.55	0.0242
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Strontium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Zinc	0.73	0.33	0.28	0.44	0.26	0.00	0.00	0.09	0
TOTAL METALS	**93.4**	**30.9**	**121.1**	**81.8**	**33.3**	**11.0**	**54.3**	**32.9**	

MCLB, ALBANY, GA - Industrial Hygiene Metal Data (microgram/cu.meter)
Corrected for Blank Values

METAL	Samples Taken Near Welder (about 2 feet) 18-Nov	19-Nov	20-Nov	21-Nov	Aver. Near Welder	Samples taken Away From Welder (about 10 feet) 18-Nov	19-Nov	20-Nov	21-Nov	Average Away	Blank Values-wk1 (microgram)	Blank Values-wk2 (microgram)	Average Blank
Aluminum	2.962	5.024	8.874	2.517	4.844	3.531	1.269	7.564	4.758	4.280	3.36	0	1.68
Antimony	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
Arsenic	0.064	0.212	0.103	0.000	0.095	0.094	0.112	0.097	0.000	0.076	0	0	0
Barium	0.094	0.111	0.270	0.000	0.119	0.104	0.072	0.233	0.000	0.102	0	0	0
Beryllium	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0	0
Cadmium	0.000	0.000	0.019	0.000	0.005	0.011	0.000	0.015	0.000	0.007	0	0	0
Chromium (total)	1.175	1.374	1.778	1.097	1.356	1.548	0.429	1.573	1.435	1.246	0.3	0.299	0.2995
Chromium (+6)	0.002	0.542	0.058	0.025	0.157	0.023	0.000	0.038	0.000	0.015	0.037		0.037
Cobalt	0.000	0.069	0.090	0.000	0.040	0.061	0.000	0.131	0.000	0.048	0	0	0
Copper	3.598	6.309	3.997	5.657	4.890	4.703	3.702	3.305	5.903	4.403	0	0	0
Iron	377.5	568.8	742.0	467.2	538.9	612.1	205.5	475.7	581.0	468.6	2.83	1.64	2.235
Lead	0.053	0.074	0.096	0.000	0.056	0.070	0.000	0.087	0.000	0.039	0	0	0
Magnesium	1.125	1.215	1.944	0.000	1.071	1.256	0.699	1.664	2.357	1.494		0	0
Manganese	14.848	24.105	28.749	65.662	33.341	14.778	5.724	28.496	55.908	26.227	0.0358	0	0.0179
Molybdenum	2.670	2.571	4.122	2.223	2.897	3.497	1.046	3.106	4.141	2.947	0	0	0
Nickel	7.842	8.483	14.287	8.726	9.835	10.034	2.449	9.590	14.335	9.102	0.0242	0	0.0121
Selenium	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
Silver	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
Strontium	0.000	0.000	0.062	0.000	0.016	0.000	0.000	0.000	0.000	0.000	0	0	0
Vanadium	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0
Zinc	0.000	0.000	1.652	0.000	0.413	0.000	0.000	2.237	0.000	0.559	0	0	0
TOTAL METALS	**411.9**	**618.9**	**808.1**	**553.1**	**598.0**	**651.9**	**221.0**	**533.9**	**669.8**	**519.1**			

ANAD, Anniston, AL - Industrial Hygiene Metal Data (microgram/cu.meter)
Corrected for Blank Values

METAL	Samples Taken Near Welder (about 2 feet)					Samples taken Away From Welder (about 10 feet)					Blank Values (microgram)
	21-Oct	22-Oct	23-Oct	24-Oct	Aver. Near Welder	21-Oct	22-Oct	23-Oct	24-Oct	Average Away	
Aluminum	2.52	7.41	12.18	10.85	8.24	4.70	2.89	4.24	3.89	3.93	8.04
Antimony	0.00	0.00	0.09	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0
Arsenic	0.00	0.00	0.29	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0
Barium	0.00	0.00	0.22	0.13	0.09	0.08	0.00	0.07	0.07	0.05	0
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Chromium (total)	0.54	0.79	3.66	1.14	1.53	0.92	0.58	0.97	0.67	0.78	0
Chromium (+6)	0.24	0.05	0.21	0.05	0.14	0.10	0.08	0.09	0.04	0.08	0.0311
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Copper	0.00	0.64	7.74	3.12	2.87	0.84	0.00	1.86	0.98	0.92	0
Iron	204.47	361.04	1347.49	234.68	536.92	434.48	262.63	383.88	139.74	305.18	1.04
Lead	0.18	0.20	0.35	0.21	0.23	0.33	0.15	0.16	0.13	0.19	0
Manganese	66.89	107.37	145.57	56.69	94.13	153.35	78.62	69.61	36.33	84.48	0
Molybdenum	0.00	0.00	0.93	0.18	0.28	0.07	0.00	0.18	0.07	0.08	0
Nickel	3.29	5.72	11.02	3.91	5.99	8.05	4.18	4.39	2.44	4.77	0
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Strontium	0.00	0.00	0.06	0.17	0.06	0.00	0.00	0.00	0.00	0.00	0
Vanadium	0.00	0.00	0.30	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0
Zinc	0.00	0.80	1.40	0.92	0.78	1.04	0.66	0.77	0.00	0.62	0
TOTAL METALS	**278.1**	**484.0**	**1531.5**	**312.0**	**651.4**	**604.0**	**349.8**	**466.2**	**184.4**	**401.1**	

ANAD, Anniston, Al - Industrial Hygiene Metal Data (microgram/cu.meter)
Corrected for Blank Values

	Samples Taken Near Welder (about 2 feet)						Samples taken Away From Welder (about 10 feet)						
METAL	27-Oct	28-Oct	29-Oct	30 Oct (aluminum)	30 Oct (blank run)	Aver. Near Welder w/o 30 Oct	27-Oct	28-Oct	29-Oct	30 Oct (Aluminum)	30 Oct (blank run)	Average Away w/o 30 Oct	Blank Values (microgram)
Aluminum	68.48	7.16	22.60	643.60	12.70	32.75	7.53	5.01	9.88	173.00	16.01	7.47	3.36
Antimony	0.00	0.00	0.06	<0.1	<0.1	0.02	0.00	0.00	0.00	<0.1	<0.2	0.00	0
Arsenic	0.00	0.00	0.00	<0.6	<0.7	0.00	0.00	0.00	0.00	<0.6	<0.8	0.00	0
Barium	0.56	0.11	0.16	<0.1	<0.1	0.28	0.00	0.07	0.00	<0.1	<0.2	0.02	0
Beryllium	0.00	0.00	0.00	<0.1	<0.1	0.00	0.00	0.00	0.00	<0.1	<0.2	0.00	
Cadmium	0.00	0.00	0.00	<0.6	<0.7	0.00	0.00	0.00	0.00	<0.6	<0.8	0.00	0
Chromium (total)	2.27	1.24	4.43	1.87	<0.7	2.65	0.00	0.82	0.85	0.59	<0.8	0.56	0.3
Chromium (+6)	0.00	0.18	0.20	0.11	0.00	0.12	0.07	0.26	0.11	0.03	0.00	0.15	0.0608
Cobalt	0.00	0.00	0.00	<0.6	<0.7	0.00	0.00	0.00	0.00	<0.6	<0.8	0.00	0
Copper	9.31	2.94	3.17	1.77	<1.5	5.14	0.00	1.94	0.73	<1.2	<1.6	0.89	0
Iron	794.13	570.62	1107.62	20.50	1.69	824.12	5.51	300.56	228.92	15.06	1.48	178.33	2.83
Lead	0.49	0.30	0.33	<0.1	<0.1	0.37	0.00	0.31	0.15	<0.1	<0.2	0.15	0
Manganese	143.94	73.02	118.26	2.45	<0.7	111.74	2.58	67.84	58.49	1.70	<0.8	42.97	0.0358
Molybdenum	0.35	0.20	1.91	<0.1	<0.1	0.82	0.00	0.10	0.26	<0.1	<0.2	0.12	0
Nickel	16.25	5.29	14.59	<1.1	<1.5	12.04	0.00	4.39	3.73	<1.2	<1.6	2.71	0.0242
Selenium	0.00	0.00	0.00	<0.6	<0.7	0.00	0.00	0.00	0.00	<0.6	<0.8	0.00	0
Silver	0.00	0.00	0.00	<0.6	<0.7	0.00	0.00	0.00	0.00	<0.6	<0.8	0.00	0
Strontium	0.84	0.08	0.17	<0.1	<0.1	0.36	0.00	0.00	0.00	<0.1	<0.2	0.00	0
Vanadium	0.00	0.00	0.35	<0.6	<0.7	0.12	0.00	0.00	0.00	<0.6	<0.8	0.00	0
Zinc	2.08	1.04	1.16	<1.1	<1.5	1.42	0.00	1.04	0.70	<1.2	<1.6	0.58	0
TOTAL METALS	**1,038.7**	**662.2**	**1,275.0**	**670.3**	**14.4**	**992.0**	**15.7**	**382.4**	**303.8**	**190.4**	**17.5**	**234.0**	

Puget Sound Naval Shipyard, Bremerton, WA - Industrial Hygiene Metal Data (microgram/cu.meter)
Corrected for Blank Values

METAL	Samples Taken Near Welder (about 2 feet)					Samples taken Away From Welder (about 10 feet)					Blank Values (microgram)		
	10-Aug	11-Aug	12-Aug	13-Aug	**Aver. Near Welder**	10-Aug	11-Aug	12-Aug	13-Aug	**Average Away**	wk1	wk2	**AVG.**
Aluminum	13.42	13.37	20.79	11.51	14.77	10.76	11.47	17.91	11.40	12.88	5.25	0	**2.625**
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	**0**
Arsenic	0.05	0.04	0.03	0.00	0.03	0.03	0.00	0.00	0.00	0.01	0	0	**0**
Barium	0.45	0.05	0.17	0.00	0.17	0.32	0.00	0.11	0.00	0.11	0	0	**0**
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	**0**
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	**0**
Chromium (total)	0.32	0.22	0.65	0.13	0.33	0.18	0.17	0.29	0.10	0.19	0.22	0.24	**0.23**
Chromium (+6)	-0.01	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	-0.01	0.00	0.026	0.0311	**0.02855**
Cobalt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	**0**
Copper	2.45	1.56	1.57	0.00	1.40	1.85	1.45	0.00	0.00	0.82	0	0	**0**
Iron	87.86	47.66	109.06	47.23	72.95	57.87	39.61	59.73	41.45	49.67	0	0	**0**
Lead	0.19	0.05	0.22	0.00	0.12	0.06	0.05	0.11	0.00	0.06	0	0	**0**
Magnesium	5.81	3.07	6.71	0.00	3.90	5.67	2.84	6.08	0.00	3.65	0	0	**0**
Manganese	4.91	2.81	10.07	1.87	4.92	4.27	2.53	6.08	1.74	3.66	0	0	**0**
Molybdenum	0.13	0.16	1.12	0.22	0.41	0.13	0.10	0.22	0.23	0.17	0	0	**0**
Nickel	1.36	1.09	3.75	0.90	1.77	0.70	0.93	1.00	0.83	0.86	0	0.2	**0.1**
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	**0**
Silver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	**0**
Strontium	0.00	0.00	0.05	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0	0	**0**
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	**0**
Zinc	-0.25	0.00	3.59	0.00	0.84	-0.24	0.00	1.95	0.00	0.43	0	0.765	**0.3825**
TOTAL METALS	**116.7**	**70.1**	**157.8**	**61.9**	**101.6**	**81.6**	**59.2**	**93.5**	**55.7**	**72.5**			

Puget Sound Naval Shipyard, Bremerton, WA - Industrial Hygiene Metal Data (microgram/cu.meter)
Corrected for Blank Values

METAL	Samples Taken Near Welder (about 2 feet)					Samples taken Away From Welder (about 10 feet)					Blank Values (microgram)		
	16-Aug	17-Aug	18-Aug	19-Aug	Aver. Near Welder	16-Aug	17-Aug	18-Aug	19-Aug	Average Away	wk1	wk2	**AVG.**
Aluminum	0.17	0.78	1.92	2.43	1.33	0.02	0.33	1.63	2.27	1.07	5.25	0	**2.625**
Antimony	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<0.1	0	0	**0**
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<0.3	0	0	**0**
Barium	0.00	0.08	0.00	0.00	0.02	0.00	0.00	0.00	0.05	0.01	0	0	**0**
Beryllium	0.00	0.00	0.00	0.00	<0.1	0.00	0.00	0.00	0.00	<0.1	0	0	**0**
Cadmium	0.00	0.00	0.00	0.00	<0.3	0.00	0.00	0.00	0.00	<0.3	0	0	**0**
Chromium (total)	0.08	0.12	0.27	0.05	0.13	0.12	0.06	0.21	0.08	0.12	0.22	0.24	**0.23**
Chromium (+6)	-0.03	-	-	-	-0.03	-0.03	-	-	-	-0.03	0.026	0.0311	**0.02855**
Cobalt	0.00	0.00	0.00	0.00	<0.3	0.00	0.00	0.00	0.00	<0.3	0	0	**0**
Copper	0.54	0.81	1.53	0.47	0.84	0.40	0.66	1.41	0.47	0.73	0	0	**0**
Iron	18.94	46.42	38.14	32.52	34.00	13.86	37.58	34.01	31.99	29.36	0	0	**0**
Lead	0.06	0.15	0.07	0.00	0.07	0.00	0.10	0.00	0.00	0.03	0	0	**0**
Magnesium	0.86	1.87	2.20	1.86	1.70	1.00	1.71	2.06	1.91	1.67	0	0	**0**
Manganese	1.28	4.55	3.62	2.23	2.92	0.98	4.31	3.24	2.49	2.75	0	0	**0**
Molybdenum	0.13	0.10	0.24	0.00	0.12	0.10	0.07	0.21	0.00	0.10	0	0	**0**
Nickel	0.46	0.41	0.84	0.21	0.48	0.36	0.24	0.71	0.27	0.39	0	0.2	**0.1**
Selenium	0.00	0.00	0.00	0.00	<0.3	0.00	0.00	0.00	0.00	<0.3	0	0	**0**
Silver	0.00	0.00	0.00	0.00	<0.3	0.00	0.00	0.00	0.00	<0.3	0	0	**0**
Strontium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<0.1	0	0	**0**
Vanadium	1.51	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.00	<0.3	0	0	**0**
Zinc	1.32	1.27	1.20	1.16	1.24	0.63	1.08	1.01	1.19	0.98	0	0.765	**0.3825**
TOTAL METALS	**25.3**	**56.5**	**50.0**	**40.9**	**43.2**	**17.5**	**46.1**	**44.5**	**40.7**	**37.2**			

Southwest Regional Maintenance Center (SWRMC), San Diego, CA - Industrial Hygiene Metal Data (microgram/cu.meter)
Corrected for Blank Values

METAL	Samples Taken Near Welder (about 2 feet)					Samples taken Away From Welder (about 10 feet)					Blank Values (microgram)		
	28-Sep	29-Sep	30-Sep	1-Oct	Aver. Near Welder	28-Sep	29-Sep	30-Sep	1-Oct	Average Away	wk1	wk2	Avg.
Aluminum	6.37	24.13	0.00	21.38	12.97	2.11	9.87	2.44	1.89	4.08	0	0	0
Antimony	0.00	0.00	0.00	0.12	0.03	0.00	0.00	0.00	0.00	0.00	0	0	0
Arsenic	0.00	0.00	0.00	0.24	0.06	0.00	0.00	0.00	0.00	0.00	0	0	0
Barium	0.25	0.75	0.00	7.92	2.23	0.08	0.40	0.00	0.13	0.15	0	0	0
Beryllium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0
Chromium (total)	0.33	0.57	0.16	10.89	2.99	0.07	0.04	0.16	0.20	0.12	0.21	0.29	0.25
Chromium (+6)	0.03	0.21	0.00	0.17	0.10	-0.03	-0.02	0.00	-0.03	-0.02	0.049	0.045	0.047
Cobalt	0.00	0.00	0.00	0.12	0.03	0.00	0.02	0.00	0.00	0.00	0	0	0
Copper	6.40	3.10	6.17	30.88	11.64	1.87	1.26	1.65	1.62	1.60	0	0	0
Iron	122.38	302.99	142.86	1607.28	543.88	32.71	19.80	12.80	25.06	22.59	0	0	0
Lead	0.38	0.85	0.00	1.27	0.62	0.12	0.09	0.00	0.16	0.09	0	0	0
Magnesium	2.60	4.76	0.00	2.58	2.48	0.00	1.31	0.00	0.00	0.33	0	0	0
Manganese	26.79	89.55	27.85	69.68	53.47	8.19	6.10	2.03	4.33	5.16	0	0	0
Molybdenum	0.13	0.31	0.00	2.45	0.72	0.00	0.00	0.00	0.00	0.00	0	0	0
Nickel	0.70	0.34	0.17	1.82	0.76	0.25	0.13	0.19	0.12	0.17	0	0	0
Selenium	0.00	0.00	0.00	0.00	0.00	0.00	19.41	0.00	0.00	4.85	0	0	0
Silver	0.17	0.06	0.00	0.12	0.09	0.00	0.00	0.00	0.00	0.00	0	0	0
Strontium	0.00	0.12	0.00	0.32	0.11	0.00	0.00	0.00	0.00	0.00	0	0	0
Vanadium	0.00	0.09	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0	0	0
Zinc	45.66	165.75	1.71	17.22	57.58	14.48	12.95	0.32	0.48	7.06	0.98	0.719	0.8495
TOTAL METALS	**212.2**	**593.6**	**178.9**	**1774.5**	**689.8**	**59.9**	**71.4**	**19.6**	**34.0**	**46.2**			

Appendix J
Evaluation of Inverter Welding Power Supplies as a Means of Reducing Welding Fumes

Naval Surface Warfare Center - Carderock Division

NSWCCD-61-TR–2003/XX /December 2003

Evaluation of Inverter Welding Power Supplies as a Means of Reducing Welding Fumes
Survivability, Structures, and Materials Directorate Technical Report

NSWCCD-61-TR–2003/XX **/**December 2003
Survivability, Structures, and Materials Directorate Technical Report

K. Tran and G. Franke

Naval Surface Warfare Center
Carderock Division
West Bethesda, MD 20817-5700

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Administrative Information

The work described in this report was performed by the Welding and NDE Branch (Code 615) of the Survivability, Structures and Materials Directorate at the Naval Surface Warfare Center, Carderock Division (NSWCCD). The work was funded by the Environmental Security Technology Certification Program, through the U.S. Army Corps of Engineers, under MIPR W74RDV21261985. The work unit was 02-1-6150-460.

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Introduction

One of the main hazards of welding operations is the emississions of hexavalent chromium (Cr(VI)), manganese (Mn), and nickel (Ni) in the welding fume. Cr(VI) and Ni are both carcinogens that propose adverse effects to the skin and respiratory and immune systems, while repeated exposure to Mn may cause gradual brain damage. The U.S. Occupational Safety and Health Administration (OSHA) and American of Conference of Governmental and Industrial Hygienists (ACGIH) have proposed new requirements for worker exposure to these stressors. OSHA and ACGIH propose to reduce the permissible exposure limit (PEL) for Cr(VI), Mn, and Ni below their current levels.

These changes will have an impact on welding operations in many Department of Defense (DOD) facilities. As part of a DOD effort to address these anticipated changes, the Naval Facilities Engineering Service Center (NFESC), Port Hueneme, CA, and Naval Surface Warfare Center Carderock Division (NSWCCD) have collaborated to evaluate new welding power supplies that can reduce fume through close control of welding parameters.

Various new welding power supplies offer sophisticated technologies to reduce fume emissions. Pulsed inverter power supplies electronically produce precision waveforms that improve weld consistency and reduce fume emissions. Pulsed inverter power supplies have been applied to production lines with success in increased productivity and reduced fume emissions.
This effort seeks to transition new inverter power supplies into the field at a number of DOD facilities. The work described here provides details of the laboratory evaluation of two such welding systems.

Materials and Equipment

Two sets of equipment manufactured by Miller Electric Manufacturing Company (Miller) were evaluated in this study. The equipment was selected by the DOD facilities that would be using it following initial evaluation. The first set of equipment included a Miller Invision 456MP inverter power supply (456MP), Miller S-74DX (S-74DX) wire feeder, and Miller Coolmate 4 torch cooling system, along with a Binzel Ergo 50D manual gas metal arc welding (GMAW) torch, adaptor kit, and expendables. The second set of equipment included a 456MP and Miller S-60M (S-60M) Series wire feeder, along with a Profax 400 GMAW gun and expendables. Figure 1 illustrates the first set of equipment and Figure 2 illustrates the second set of equipment.

The 456MP is a pulsed inverter power supply for GMAW, pulsed GMAW, shielded metal arc welding (SMAW), and flux cored arc welding (FCAW) processes. The unit features eighteen programs with preset parameters that provided general guidelines for welding with a specific welding process, type and size of welding consumable, and shielding gas. These programs offer the option of choosing either an adaptive or non-adaptive welding mode. In the adaptive mode, the pulse frequency is automatically regulated to maintain a constant arc length, regardless of changes in wire stickout during the welding process. In the non-adaptive mode, a constant pulse frequency is maintained regardless of the arc length. The unit also includes three additional programs without preset parameters for manual GMAW, SMAW, and FCAW.

The S-74DX wire feeder is a semi-automatic wire feeder for GMAW, pulsed GMAW, and FCAW. The S-60M Series wire feeder is a semi-automatic wire feeder for GMAW, pulsed GMAW, and FCAW. The S-60M Series wire feeder also features preset programs that provide general guidelines for welding with specific types of welding wires.

Figure 1. Miller Invision 456 MP Inverter Power Supply, S-74DX Wire Feeder, and Coolmate 4

Figure 2. Miller Invision 456 MP and S-60M Wire Feeder

Welding Consumables

The wire used for this study included 0.062-inch-diameter Lincoln Electric Company (Lincoln) SuperArc LA-100™ (ER100S-G) solid wire, 0.062-inch-diameter Tri-Mark TM-811N2™ (E81T1-Ni2H8) gas shielded flux cored wire, 0.062-inch-diameter ESAB Dual Shield II-70T-12™ (E71T-1) gas shielded flux cored wire, and ESAB SpoolArc 95™ (ER100S) solid wire. Mild steel, A36, base plate material was used for all fume generation welding trials.

Procedure

Fume Generation Rate Testing

Fume generation rate (FRG) was determined in accordance to AWS F1.2 *Laboratory Method for Measuring Fume Generation Rates and Total Fume Emission of Welding and Allied Processes* [1]. The tests for fume generation rate involved the following sampling equipment:

- Conical test chamber
- Filter assembly for collecting fumes
- Pressure drop gauge

- Constant flow rate pump

Figures 3 and 4 depict the sampling equipment set-up. The preparation and test method for determining the FGR was conducted accordingly:

- A glass fiber filter, measuring 12 inches square that has been previously dried in an oven for a minimum of one hour at 200°-225°F is weighed. The filter weight is recorded.
- The consumable is weighed. The consumable weight is recorded.
- The filter pad is assembled on the fume chamber.
- The test is begun by turning on the pump and initiating the welding process. The welding process is timed to one minute from start to finish.
- After the welding process is complete, the chamber is allowed to clear for one minute.
- The pump is turned off.
- The filter is removed from the chamber and weighed.
- The remaining consumable is weighed. The remaining consumable weight is recorded.

The FGR and percent weight of fume obtained for a given weight of consumables is calculated as follows:

$$FGR = \frac{Final\ wt. of\ filter(g) - Initial\ wt. of\ filter(g)}{Test\ time(\min)}$$

$$Percent\ fume\ for\ given\ wt.\ of\ consumable = \frac{Final\ wt. of\ filter(g) - Initial\ wt. of\ filter(g)}{Initial\ wt\ of\ consumable(g) - Final\ \ wt. of\ consumable(g)} * 100$$

Figure 3. Fume Generation Rate Equipment Set Up

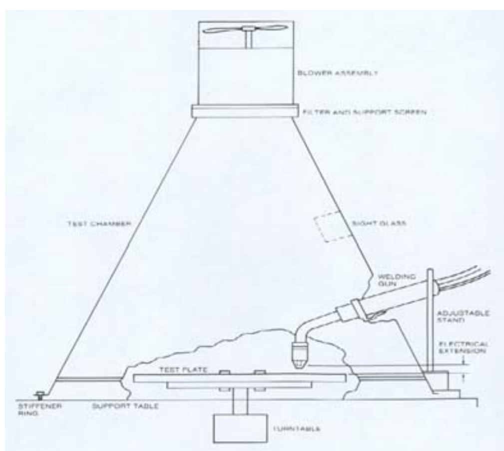


Figure 4. Fume Generation Rate Equipment Schematic [1]

Miller Invision 456 MP and S-74DX Wire Feeder

The initial effort involved an evaluation of the 456 MP and S-74DX. FGR testing was conducted with Program 20, manual GMAW, using 0.062 inch diameter SuperArc LA-100™ wire and a mixture of 95 percent argon (Ar) and 5 percent carbon dioxide (CO_2) shielding gas. The initial set of parameters chosen for the first test were 26 volts (V) and current of 300 amperes. The parameters were chosen to achieve a heat input of 40 to 50 kilojoules per inch (kJ/in) during each test. Additional tests were conducted with the current held constant and the voltage altered by either increasing or deceasing from the original value by 2 volt increments. Testing at these conditions, constant current of 300 amps with variable voltage, was commenced when a noticeable change in the FGR was observed. FGR testing continued with a new set of parameters. The current was increased to 350 amps and voltage set to 26 volts in order to maintain a heat input of 40 to 50 kJ/in. Additional testing involved holding the current constant at 350 amps and altering the voltage by either increasing or decreasing the value by 2 volt increments. Testing was commenced when a noticeable change in FGR was observed. Additional testing was conducted at constant currents of 400-, 250-, and 200-amps and varying voltage. Testing parameters are shown in Appendix A1. During the welding process, both the current and voltage could be adjusted by controls found on the S-74DX wire feeder. Any adjustments made to the current or voltage would also be reflected on the displays found on the 456MP.

The next effort involved an evaluation of the 456MP with S-74DX using a featured program with preset parameters. Program 4, intended to be used with a 0.062-inch-diameter steel welding wire and Ar-CO_2 shielding gas was evaluated with 0.062-inch-diameter SuperArc LA-100™ wire and 95% Ar - 5% CO_2 shielding gas. FGR testing with Program 4 was first conducted in the non-adaptive mode. The preset parameters of a wire feed speed of 196 inches per minute (ipm) and trim of 40 were chosen as the initial parameters. These parameters were chosen because they are in the middle range offered by Program 4. The preset parameters offered by Program 4 ranged from a 60 ipm wire feed speed with 0 trim to 400 ipm wire feed speed with 100 trim. The preset trim or arc length values between 0 to 100 are intended by Miller Electric to be a reference for the user. Tests were conducted with constant wire feed speed with variable current and voltage. A heat input between 40 and 60 kJ/in was maintained for all tests within this set of parameters. The testing parameters are shown in Appendix A2.

Testing using Program 4 was also conducted in the adaptive pulse mode with 0.062-inch-diameter SuperArc LA-100™ wire and 95% Ar - 5% CO_2 shielding gas. Two sets of preset parameters in the middle range offered by Program 4 were evaluated. A wire feed speed of 196 ipm with a 40 trim and wire feed speed of 230 ipm with 50 trim were evaluated. Tests were conducted with constant wire feed speed with variable current and voltage. The heat input was maintained between 25 and 40 kJ/in for both sets of test parameters. The testing parameters are shown in Appendix A2.

Testing using flux cored wire involved the use of Program 18 which is intended for 0.062-inch-diameter metal cored wire with Ar-CO_2 shielding gas. There are no preset parameters specifically for flux cored wire, however, the parameters for metal cored wire were considered appropriate for flux cored arc welding. An initial effort involved testing in the adaptive pulse mode with 0.062-inch-diameter ESAB Dudal Shield II-70T-12™ dual shield flux cored wire with 95% Ar - 5% CO_2 shielding gas. A wire feed speed of 230 ipm with a 40 trim was chosen, because these parameters were in the middle range of preset parameters offered by Program 18. Tests were conducted at a constant wire feed speed with variable current and voltage. The heat input was maintained between 25 and 40 kJ/in for both sets of test parameters. The test parameters are shown in Appendix A2.

Additional testing involving Program 18 was conducted with Tri-Mark TM-811N2™ flux cored wire in the adaptive pulse mode. Tests were conducted with 95% Ar - 5% CO_2 and 75% Ar - 25% CO_2 shielding gases. The parameters chosen were the middle range of preset parameters offered by Program 18. Tests were conducted at a constant wire feed speed with variable current and voltage. The parameters for tests using 95% Ar - 5% CO_2 shielding gas included wire feed speeds of 320-, 275-, 230-, 185-, and 140-ipm along with trims of 60, 50, 40, 30, and 20. For tests using 75% Ar - 25% CO_2 shielding gas, the parameters included wire feed speeds of 275-, 230-, 185-, and 140-ipm along with trims of 60, 50, 40, 30, and 20. Heat inputs for all sets of parameters were maintained between 20 and 40 kJ/in. The test parameters are shown in Appendix A3 for tests using 95% Ar - 5% CO_2 shielding gas and Appendix A4 for tests using 75% Ar - 25% CO_2 shielding gas.

Miller Invision 456 MP and S-60M Wire Feeder

FGR testing results were not obtained for the 456MP and S-60M wire feeder. Testing with the 456MP and S-60M wire feeder using 0.045-inch-diameter ESAB SpoolArc 95 wire was unsuccessful. The 456MP power supply and S-60M wire feeder were found to be incompatible. A number of trial and error experiments were conducted using featured Program 16 for 0.045-inch-diameter steel wire were unsuccessful. Attempts to use the 456MP in manual GMAW mode with the S-60M wire feeder were also unsuccessful. Setting the 456MP in manual GMAW mode with the S-60M wire feeder set to the appropriate program for 0.045-inch-diameter steel wire were also unsuccessful. It was determined from subsequent discussions with the manufacturer that an Invision 456 P is the appropriate "slave" welding power supply to be used with the S-60M series of intelligent wire feeders.

Welding Qualification

Welding qualification involved using the 456 MP power supply and S-74DX wire feeder with Program 18 in adaptive pulse mode. Program 18 was chosen to be the most appropriate featured program setting for flux cored welding. The welding qualification was conducted with the GMAW process in the vertical position using 0.062-inch-diameter Tri-Mark TM-811N2™ flux cored wire and one-inch-thick A36 base plate. A 12-inch-long K-type joint with a ¼ inch root opening and copper backing bar was used as the welding qualification joint design. Figure 5 illustrates the welding joint. Initial efforts involved a number of welding trials using different wire feed speeds, current, and voltage settings, attempting to achieve the lowest FGR with practical welding parameters, and 95% Ar - 5% CO_2 shielding gas. Welding trials with different parameters were used to find the optimal parameter settings for depositing a quality weld bead. After numerous unsuccessful attempts with different parameter settings using 95% Ar - 5% CO_2, the shielding gas was changed to 75% Ar - 25% CO_2. A number of welding trials with different parameters using 75% Ar - 25% CO_2 were also conducted. Final parameters that resulted in the best weld bead quality were established to be preset parameters of a wire feed speed of 185 ipm with 30 trim. The current was adjusted to a range of 175 to 180 amps and voltage between 24 and 25 V. The welding qualification plate was completed with eight passes. Table 1 illustrates the different parameters used to obtain the optimal settings and final parameters used to compete the welding qualification plate. The welding procedure is shown in Appendix B.

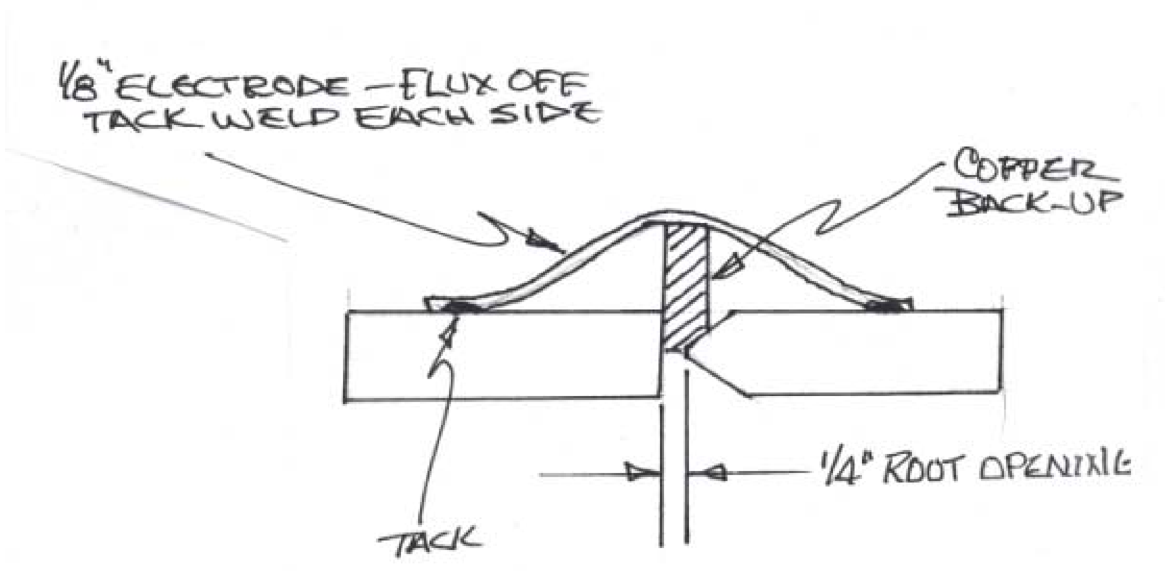


Figure 5. K-Type Joint Welding Qualification Plate [2]

Table 1. Welding Qualification Parameters

Pass	Shielding Gas	Wire Feed Speed (ipm)	Voltage (V)	Current (Amps)	Weld Time (min:sec)	Interpass Temperature (°F)
Power Supply: Miller Invision 456 MP			**Wire Feeder:** Miller S-74DX			
Welding Process: GMAW Adaptive Pulse			**Plate Material:** A36 Steel		**Filler Wire:** 0.062-inch Tri-Mark TM-811N2™	
Trial Passes	95% Ar - 5% CO_2	185	26	200	Not obtained	Not obtained
		230	25	220	Not obtained	Not obtained
		230	25	220	Not obtained	Not obtained
		200	22	190	Not obtained	Not obtained
		200	20	180	Not obtained	Not obtained
		190	22	180	Not obtained	Not obtained
		195	23	185	Not obtained	Not obtained
		195	22	180	Not obtained	Not obtained
		200	22	195-200	Not obtained	Not obtained
Trial Passes	75% Ar - 25% CO_2	200	22	195-200	Not obtained	Not obtained
		140	25	150	Not obtained	Not obtained
		140	25	150	Not obtained	Not obtained
		220	27	205	Not obtained	Not obtained
		200	27	200	Not obtained	Not obtained
		180	26	185	Not obtained	Not obtained
		170	26	170	Not obtained	Not obtained
		170	25	170	Not obtained	Not obtained
		175	24	170	Not obtained	Not obtained
1		175	24	170	2:40	Not obtained
2		175	24	170	2:45	Not obtained
3		175	24	170	2:31	Not obtained
4		175	24.3	175	3:50	Not obtained
5		175	24.5	176	2:50	220
6		175	24.4	177	2:45	215
7		175	24.2	177	2:41	205
8		175	24.4	180	4:30	Not obtained

Results and Discussion

After data was collected for each welding trial, the FGR was determined gravimetrically using the difference between the initial and final weights of the glass filters and calculated as previously noted. The percent fume for a given weight of consumable was also calculated in a similar manner. The calculated FGR values were plotted against the voltage as shown in Figures 6, 7, 8, and 9. The results indicate that the parameter settings and shielding gas can have a significant effect on the FGR.

Figure 6 illustrates a graph of the FGR versus the voltage for welding trials conducted with the 456MP and S-74DX using Program 20 with 0.062-inch SuperArc LA-100™ wire. The circled data points indicate the initial voltages chosen for the set of parameters. Within each set of parameters, the current was held constant while the voltage was altered either by increasing it in 2 volt increments, as previously noted. The welding trials conducted at the higher travel speeds with constant currents of 350 and 400 amps showed similar trends. The results indicate that within a voltage range that is appropriate for these wire feed speeds and currents, an optimal voltage value that generates the lowest fumes exists. The voltage that generates the lowest FGR for both sets of parameters is approximately near the middle within the range of tested voltages. A voltage value of 32 V produces the lowest FGR for both set of parameters.

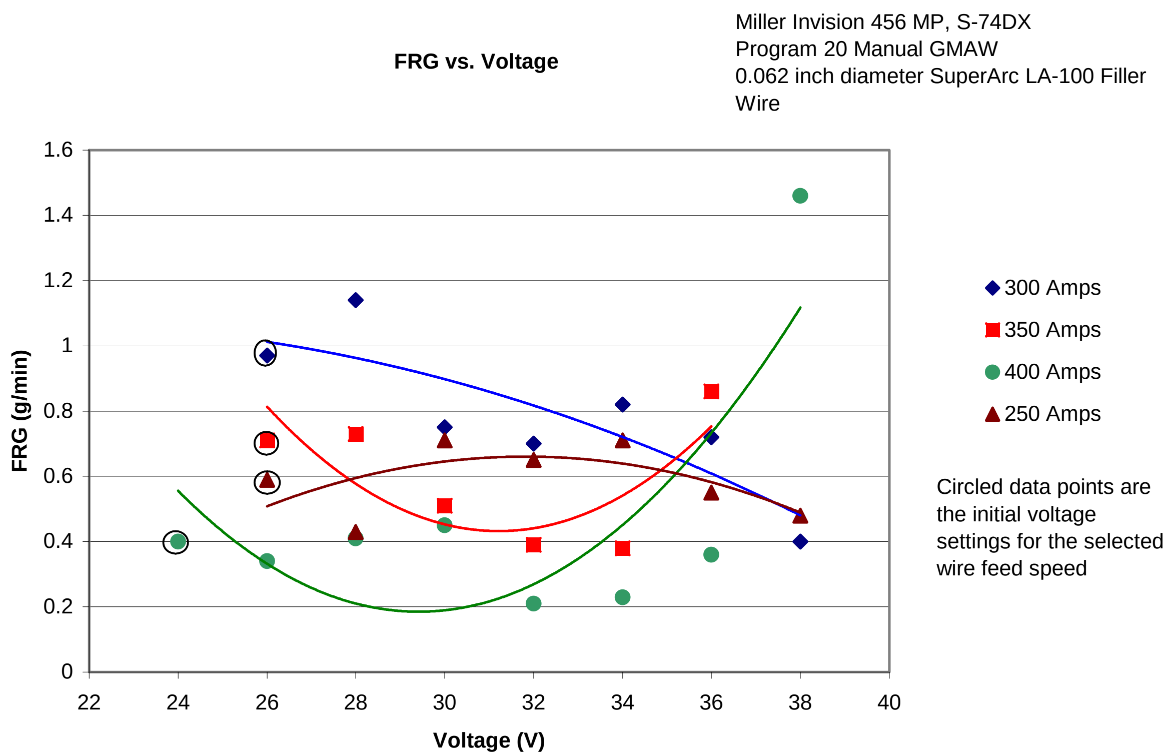


Figure 6. FGR vs. Voltage for Superarc LA-100TM Wire Using the Miller Invision 456 MP Power Supply and S-74DX Wire Feeder (Program 20)

In contrast, for the welding trials at lower wire feed speeds and current, similar trends indicate that the optimal value is at a higher voltage. Lower values of FGR were observed at 38 volts for wire feed speeds between 122 and 188 ipm and currents of 250 and 300 amps.

The results obtained for welding trials evaluated using Program 4 and 0.062-inch SuperArc LA-100^{TM} wire with the 456MP and S-74DX are shown in Figure 7. The circled data points indicate the initial program voltage settings for the selected wire feed speed and trim parameters. The graph of FGR values versus the voltage indicates similar trends for welding trials conducted in the adaptive pulse mode with constant wire feed speed. The results using preset parameters of 196 ipm with 40 trim and 230 ipm wire feed speed with 50 trim indicate that within a voltage and current range for these parameter settings, an optimal voltage and current setting combination exists that generates the lowest fumes. The voltage and current values that generate the lowest FGR for both sets of parameters are approximately near the middle within the range of tests voltages and currents. A voltage value of 30 V and 300 Amps produced the lowest FGR value at 196 ipm wire feed speed and 40 trim. At 230 ipm wire feed speed and 50 trim, a voltage of 33 V and 340 Amps produced the lowest FGR. The welding trials conducted in the non-adaptive pulse mode with constant wire feed speed indicates a more linear trend in which the FGR increases with increasing voltage and current. These results for both adaptive and non-adaptive welding trials indicate that even if the preset parameters are utilized, the voltage and current have to be adjusted in order to establish the optimal parameters that will generate the lowest FGR values.

Figure 7 also illustrates the results obtained for welding trials using Program 18 with ESAB II-70T-12™ wire with the 456 MP and S-74DX. The welding trials were conducted in the adaptive pulse mode with constant wire feed speed. These results using preset parameters of 230 ipm wire feed speed and 40 trim indicated that within a range of voltages and current, optimal voltage and current settings will generate the lowest FGR. In this case, the lowest FGR corresponded to the preset parameters. The initial program voltage of 27 V and current of 265 Amps for the conditions of 230 ipm wire feed speed and 40 trim yielded the lowest FGR.

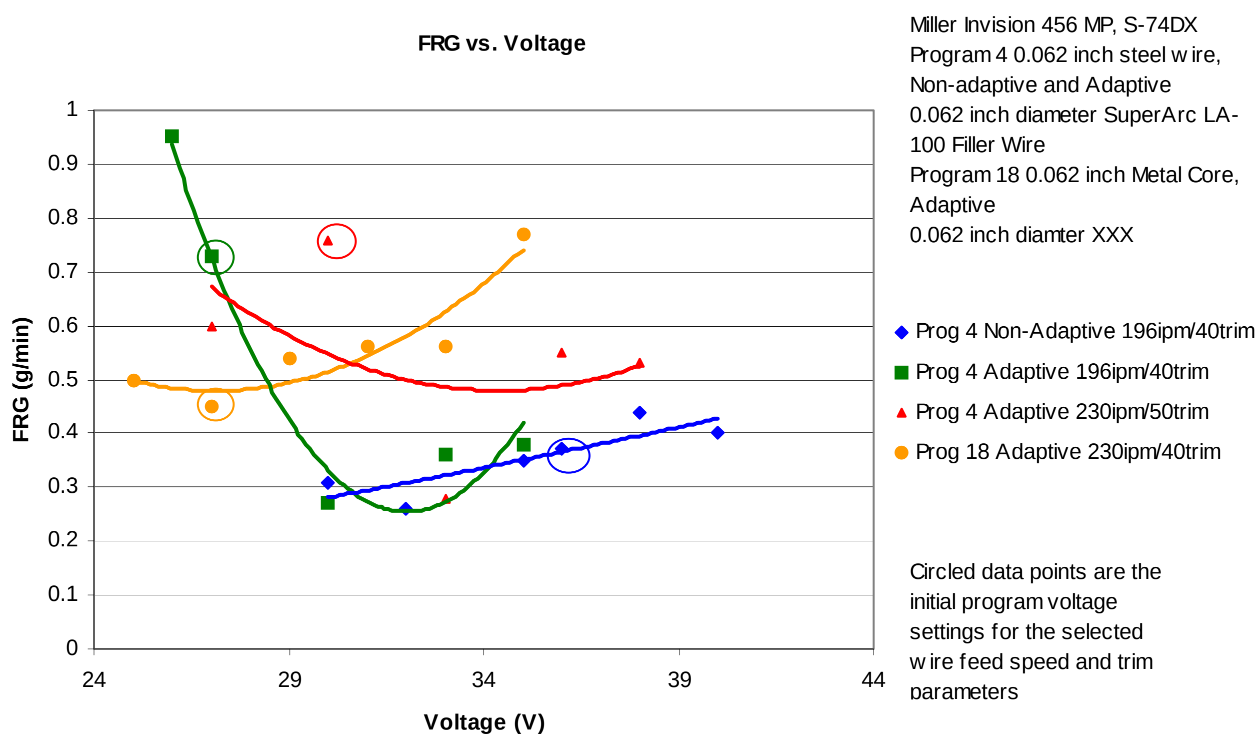


Figure 7. FGR vs. Voltage for Miller 456 MP Power Supply, Programs 4 and 18, using SuperArc LA-100™ and ESAB Dual Shield II-70T-12™

A graph of FGR vs. voltage from welding trials obtained for TM-811N2™ flux cored wire, using Program 18 with the 456 MP and S-74DX, is shown in Figure 8. The circled data points indicate the initial program voltage settings for the selected wire feed speed and trim parameters. Welding trials were conducted with 95% Ar - 5% CO_2 shielding gas and constant current. The results indicate a general trend for the all preset parameters. The results indicate that within a voltage and current range for these parameter settings, an optimal voltage and current setting combination exists that generate the lowest fumes. The voltage and current values that generate the lowest FGR for both sets of parameters are approximately near the middle within the range of test voltages and currents. The results also indicate that even if the preset parameters are utilized, the voltage and current have to be adjusted in order to establish the optimal parameters that will generate the lowest FGR values.

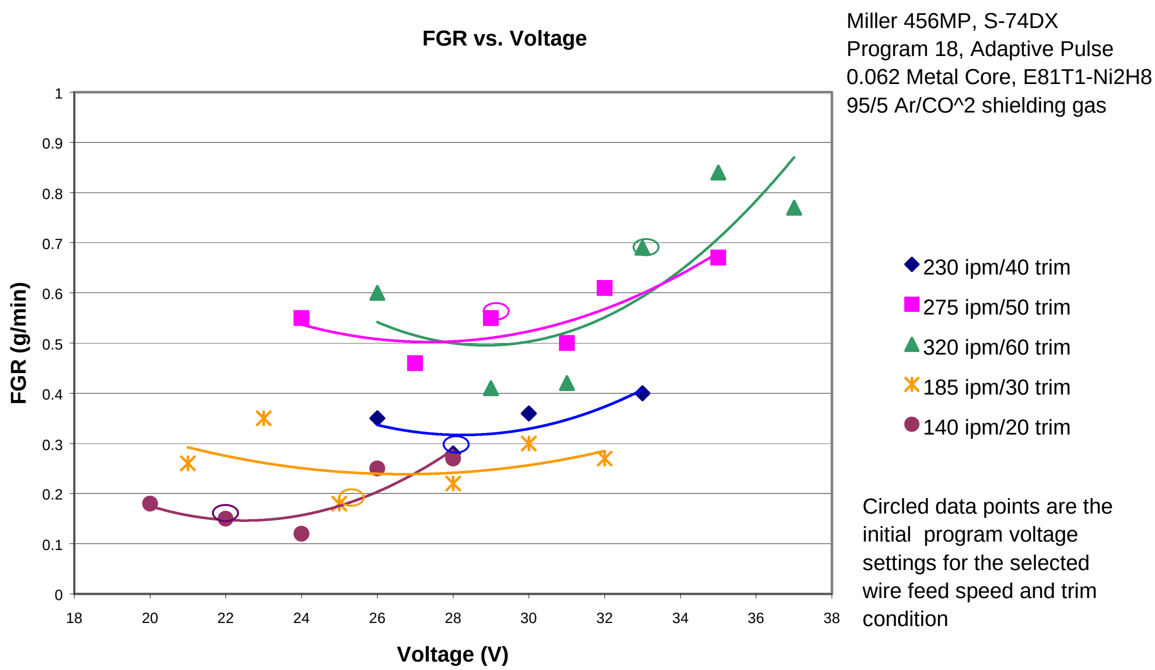


Figure 8. FGR vs. Voltage for TM-811N2 Wire With 95% Ar - 5% CO2 Shielding Gas, Program 18, Miller 456 MP Power Supply

Figure 9 illustrates the FGR vs. Voltage for welding trials obtained for TM-811N2^{TM} wire using Program 18 with the 456 MP and S-74DX. The circled data points indicate the initial program voltage settings for the selected wire feed speed and trim parameters. Welding trials were conducted with 75% Ar - 25% CO_2 shielding gas and constant current. The results indicate a general trend for the preset parameters. The results indicate a linear trend with FGR increasing with increased voltage and current settings. For a given set of preset parameters, the lowest voltage and current values generate the lowest FGR. The results also indicate that even if the preset parameters are utilized, the voltage and current have to be adjusted in order to establish the optimal parameters that will generate the lowest FGR values.

A comparison of Figure 8 and 9 indicates that shielding gas has a significant effect on FGR. Data collected for welding trials using 95% Ar - 5% CO_2 shielding gas resulted in noticeably lower FGR than data obtained from welding trials conducted with 75% Ar - 25% CO_2 shielding gas. The same preset parameters, current, and voltage were utilized to conduct the welding trials with both shielding gases. However, it is noted that even though welding trials with 95% Ar - 5% CO_2 shielding gas produced lower FGR, the gas was not appropriate for welding the qualification plate. While FGR tests showed good results for bead on plate welding conditions, attempts to optimize the welding parameters using 95% Ar - 5% CO_2 shielding gas for welding the qualification plate were unsuccessful. The use of 95% Ar - 5% CO_2 produced inadequate weld penetration that resulted in unacceptable weld quality with a non-uniform, uneven appearance. Weld quality and appearance was significantly improved by changing the shielding gas to 75% Ar - 25% CO_2. In addition, the DOD facility that will be using this equipment welds with 75% Ar - 25% CO_2 shielding in their applications. The use of 75% Ar - 25% CO_2 with optimal parameters obtained through trial and error provided the best conditions for producing a quality weld. It should be noted here that additional work with the 95% Ar - 5% CO_2 shielding gas may have achieved acceptable welding conditions, but that path was discontinued when it was learned that the other shielding gas was used in production applications.

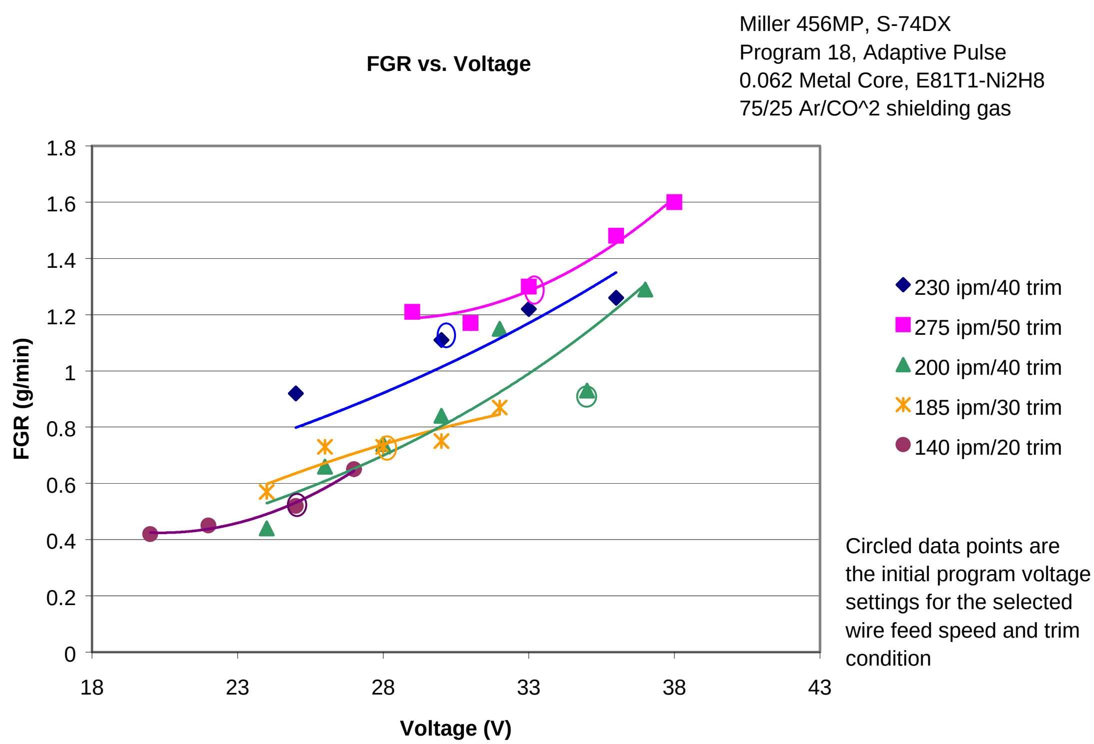


Figure 9. FGR vs. Voltage for TM-811N2TM Wire with 75% Ar - 25% CO2 Shielding Gas, Program 18, Miller 456 MP Power Supply

Summary

This effort involved the evaluation of a Miller Invision 456 MP inverter power supply and Miller S-74DX wire feeder along with other welding equipment and expendables. Work involved the use of this equipment with various types of filler wire to perform FGR welding trials and welding qualification. The use of Lincoln SuperArc LA-100™ solid wire in the manual GMAW mode at constant current and variable voltage indicated two trends. At higher currents, the results indicate that within a voltage range, an optimal voltage that generates the lowest fumes exists. At lower currents, FGR increased with increasing voltage. Welding trials conducted with a preset welding program in the adaptive mode also showed similar trends using Lincoln SuperArc LA-100™ solid wire and Tri-Mark TM-811N2™ flux cored wire. The results indicate that within a voltage and current range for given preset parameters, an optimal voltage and current setting combination exists that generates the lowest fumes. The results also indicate that even if the preset parameters are utilized, the voltage and current have to be adjusted in order to establish the optimal parameters that will generate the lowest FGR values. Welding in the non-adaptive mode with Lincoln SuperArc LA-100™ solid wire showed a more linear trend in which FGR increased with increasing voltage and current. The use of 95% Ar - 5% CO_2 shielding gas was found to produce lower FGR than 75% Ar - 25% CO_2 shielding gas. However, the use of 95% Ar - 5% CO_2 was not appropriate for welding the K-type joint qualification plate. The use of 75% Ar - 25% CO_2 shielding gas provided better weld penetration that resulted in higher weld quality with a uniform, smooth appearance, although FGR was higher.

Work also included the evaluation of the Miller Invision 456 MP inverter power supply with a Miller S-60M Series wire feeder with other welding equipment and expendables. Testing with the 456 MP and S-60M wire feeder using 0.045-inch-diameter ESAB SpoolArc 95 wire was unsuccessful. The 456 MP power supply and S-60M wire feeder were found to be incompatible. A number of trial and error experiments were conducted using the appropriate preset program for 0.045 inch diameter steel wire were unsuccessful. Attempts to use the 456 MP in manual GMAW mode with the S-60M wire feeder were also unsuccessful. The use of the 456 MP in manual GMAW mode with the S-60M wire feeder set to the appropriate preset program for 0.045 inch diameter steel wire were also unsuccessful. IT was learned that the Miller Invision 456 P is the appropriate “slave” power supply to use with the S-60M series wire feeders.

References

AWS F1.2:1999, Laboratory Method for Measuring Fume Generation Rates and Total Fume Emissions of Welding and Applied Processes, American Welding Society, 1999.

Correspondence received from Anniston Army Depot, Anniston, AL, September 2003.

Appendix A1

Test No.	Amperage (Amps)	Voltage (V)	Travel Speed (in/min)	Heat Input (Kj)	Wire Feed Speed (in/min)	Approximate Avg. Wire Wt (g)	Time (min)	Filter Beginning Wt (g)	Filter Final Wt (g)	Fume Wt (g)	FRG (g)	Notes
400-24	400	24	12.50	46.08	295	117	1.0	11.2	11.6	0.40	0.40	Initial Voltage
400-26	400	26	13.50	46.22	322	117	1.0	10.06	10.4	0.34	0.34	
400-28	400	28	14.50	46.34	321	117	1.0	11.39	11.8	0.41	0.41	
400-30	400	30	15.50	46.45	315	117	1.0	10.42	10.87	0.45	0.45	
400-32	400	32	16.50	46.55	309	117	1.0	11.77	11.98	0.21	0.21	
400-34	400	34	17.50	46.63	275	117	1.0	10.58	10.81	0.23	0.23	
400-36	400	36	18.50	46.70	256	117	1.0	11.33	11.69	0.36	0.36	
400-38	400	38	19.50	46.77	235	117	1.0	11.02	12.48	1.46	1.46	
250-26	250	26	8.50	45.88	136	44	1.0	11.47	12.06	0.59	0.59	Initial Voltage
250-28	250	28	9.00	46.67	133	44	1.0	11.38	11.81	0.43	0.43	
250-30	250	30	10.00	45.88	132	44	1.0	10.45	11.16	0.71	0.71	
250-32	250	32	10.50	45.71	132	44	1.0	10.98	11.63	0.65	0.65	
250-34	250	34	11.00	46.36	127	44	1.0	11.77	12.48	0.71	0.71	
250-36	250	36	12.00	45.00	116	44	1.0	11.03	11.58	0.55	0.55	
250-38	250	38	12.50	45.60	121	44	1.0	10.37	10.85	0.48	0.48	
200-36	200	36	9.00	48.00	94	37	1.0	9.96	10.42	0.46	0.46	
200-26	200	26	7.00	44.57	99	37	1.0	11.86	12.34	0.48	0.48	

Miller Invision 456 MP Power Supply, Program 20 Manual GMAW
Miller S-74DX Wire Feeder
95/5 Ar/CO_2 Shielding Gas
Lincoln SuperArc 100 (MIL-100S-1), 0.062 inch diameter filler wire, Heat No. ED010996

Appendix A1 (Continued)

Test No.	Amperage (Amps)	Voltage (V)	Travel Speed (in/min)	Heat Input (Kj)	Wire Feed Speed (in/min)	Approximate Avg. Wire Wt (g)	Time (min)	Filter Beginning Wt (g)	Filter Final Wt (g)	Fume Wt (g)	FRG (g)	Notes
300-26	300	26	10.00	46.80	188	69	1.0	10.27	11.24	0.97	0.97	Initial Voltage
300-28	300	28	11.00	45.82	187	69	1.0	10.6	11.74	1.14	1.14	
300-30	300	30	12.00	45.00	180	69	1.0	10.73	11.48	0.75	0.75	
300-32	300	32	13.00	44.31	172	69	1.0	10.46	11.16	0.7	0.7	
300-34	300	34	14.00	43.71	160	69	1.0	10.99	11.81	0.82	0.82	
300-36	300	36	15.00	43.20	148	69	1.0	9.95	10.67	0.72	0.72	
300-38	300	38	15.00	45.60	170	69	1.0	9.99	10.39	0.4	0.4	
350-26	350	26	12.00	45.50	255	87	1.0	10.64	11.35	0.71	0.71	Initial Voltage
350-28	350	28	13.00	45.23	255	87	1.0	11.07	11.8	0.73	0.73	
350-30	350	30	14.00	45.00	221	87	1.0	10.18	10.69	0.51	0.51	
350-32	350	32	15.00	44.80	217	87	1.0	10.94	11.33	0.39	0.39	
350-34	350	34	16.00	44.63	194	87	1.0	10.45	10.83	0.38	0.38	
350-36	350	36	17.00	44.47	184	87	1.0	11.66	12.52	0.86	0.86	

Appendix A2

Test No.	Program Wire Feed Speed/Trim	Wire Dia (in)	Amperage (Amps)	Voltage (V)	Travel Speed (in/min)	Heat Input (Kj)	Wire Feed Speed (in/min)	Wire Wt Used (g)	Time (min)	Filter Beginning Wt (g)	Filter Final Wt (g)	Fume Wt (g)	FGR (g/min)	Percent Fume (%)	Notes
196-40-N-A	196 ipm/40 trim	0.062	270	30	12.00	40.50	196	77.80	1.0	10.53	10.84	0.31	0.31	0.40	
196-40-N-B	196 ipm/40 trim	0.062	304	32	10.00	58.37	196	77.80	1.0	11.39	11.65	0.26	0.26	0.33	
196-40-N-C	196 ipm/40 trim	0.062	300	35	10.00	63.00	196	77.80	1.0	10.13	10.48	0.35	0.35	0.45	Initial program voltage and current settings
196-40-N-D	196 ipm/40 trim	0.062	320	36	13.00	53.17	196	77.80	1.0	10.84	11.21	0.37	0.37	0.48	
196-40-N-E	196 ipm/40 trim	0.062	324	38	14.00	52.77	196	77.80	1.0	11.2	11.64	0.44	0.44	0.57	
196-40-N-F	196 ipm/40 trim	0.062	332	40	15.00	53.12	196	77.80	1.0	10.94	11.34	0.4	0.4	0.51	

Miller Invision 456 MP Power Supply, Program 4, Non-adaptive pulse GMAW, 062 inch diameter steel wire
Miller S-74DX Wire Feeder
95/5 Ar/CO_2 Shielding Gas
Lincoln SuperArc 100 (MIL-100S-1), 0.062 inch diameter filler wire, 0.29 lb/in^3 density, Heat No. ED010996

Appendix A2 (continued)

Miller Invision 456 MP Power Supply, Program 4, Adaptive pulse GMAW, 0.062 inch diameter steel wire
Miller S-74DX Wire Feeder
95/5 Ar/CO_2 Shielding Gas
Lincoln SuperArc 100 (MIL-100S-1), 0.062 inch diameter filler wire, 0.29 lb/in^3 density, Heat No. ED010996

Test No.	Program Wire Feed Speed/Trim	Amperage (Amps)	Voltage (V)	Travel Speed (in/min)	Heat Input (Kj)	Wire Feed Speed (in/min)	Wire Wt Used (g)	Time (min)	Filter Beginning Wt (g)	Filter Final Wt (g)	Fume Wt (g)	FGR (g/min)	Percent Fume (%)	Notes
196-40-A-A	196 ipm/40 trim	260	26	9.00	45.07	196	77.80	1.0	10	10.95	0.95	0.95	1.22	
196-40-A-B	196 ipm/40 trim	274	27	10.00	44.39	196	77.80	1.0	9.97	10.70	0.73	0.73	0.94	Initial program voltage and current settings
196-40-A-C	196 ipm/40 trim	300	30	11.00	49.09	196	77.80	1.0	10.86	11.13	0.27	0.27	0.35	
196-40-A-D	196 ipm/40 trim	315	33	13.00	47.98	196	77.80	1.0	11.15	11.51	0.36	0.36	0.46	
196-40-A-E	196 ipm/40 trim	325	35	15.00	45.50	196	77.80	1.0	9.74	10.12	0.38	0.38	0.49	
230-50-A-A	230 ipm/50 trim	300	27	9.00	54.00	230	91.30	1.0	9.75	10.35	0.60	0.60	0.66	
230-50-A-B	230 ipm/50 trim	315	30	11.00	51.55	230	91.30	1.0	10.84	11.60	0.76	0.76	0.83	Initital program voltage and current settings
230-50-A-C	230 ipm/50 trim	340	33	12.00	56.10	230	91.30	1.0	11.4	11.68	0.28	0.28	0.31	
230-50-A-D	230 ipm/50 trim	360	36	14.00	55.54	230	91.30	1.0	11.37	11.92	0.55	0.55	0.60	
230-50-A-E	230 ipm/50 trim	377	38	15.00	57.30	230	91.30	1.0	10.89	11.42	0.53	0.53	0.58	

Appendix A2 (continued)

Miller Invision 456 MP Power Supply, Program 18, Adaptive pulse GMAW, 0.062 inch diameter metal core wire
Miller S-74DX Wire Feeder
95/5 Ar/CO_2 Shielding Gas
ESAB II-71T-12 (E71T-1), 0.062 inch diameter filler wire, 0.25 lb/in^3 density, Heat No. 51557

Test No.	Program Wire Feed Speed/Trim	Amperage (Amps)	Voltage (V)	Travel Speed (in/min)	Heat Input (Kj)	Wire Feed Speed (in/min)	Wire Wt Used (g)	Time (min)	Filter Beginning Wt (g)	Filter Final Wt (g)	Fume Wt (g)	FGR (g/min)	Percent Fume (%)	Notes
230-40-A-A-Flux	230 ipm/40trim	250	25	7.00	53.57	230	78.70	1.0	10.02	10.52	0.5	0.5	0.64	
230-40-A-B-Flux	230 ipm/40trim	265	27	7.00	61.33	230	78.70	1.0	9.84	10.29	0.45	0.45	0.57	Initial program voltage and current setting
230-40-A-C-Flux	230 ipm/40trim	270	29	9.00	52.20	230	78.70	1.0	10.74	11.28	0.54	0.54	0.69	
230-40-A-D-Flux	230 ipm/40trim	280	31	9.00	57.87	230	78.70	1.0	9.98	10.54	0.56	0.56	0.71	
230-40-A-E-Flux	230 ipm/40trim	280	33	9.00	61.60	230	78.70	1.0	10.82	11.38	0.56	0.56	0.71	
230-40-A-F-Flux	230 ipm/40trim	280	35	10.00	58.80	230	78.70	1.0	10.92	11.69	0.77	0.77	0.98	

Appendix A3

Appendix A3 (continued)

Miller Invision 456 MP Power Supply, Program 18, Adaptive pulse GMAW, 0.062 inch diameter metal core wire
Miller S-74DX Wire Feeder
95/5 Ar/CO_2 Shielding Gas
Tri-Mark TM-811N2 (E81T1-Ni2H8 filler wire, 0.23 lb/in^3 density, Heat No. S283719-K29

Test No.	Program Wire Feed Speed/Trim	Amperage (Amps)	Voltage (V)	Travel Speed (in/min)	Heat Input (Kj)	Wire Feed Speed (in/min)	Wire Wt Used (g)	Time (min)	Filter Beginning Wt (g)	Filter Final Wt (g)	Fume Wt (g)	FGR (g/min)	Percent Fume (%)	Notes
FC-230-40-1	230 ipm/40trim	233	28	13.00	30.11	230	73.58	1.0	10.69	10.97	0.28	0.28	0.38	Initial voltage and current settings
FC-230-40-2	230 ipm/40trim	233	30	12.00	34.95	230	73.58	1.0	10.57	10.93	0.36	0.36	0.49	
FC-230-40-3	230 ipm/40trim	260	33	11.50	44.77	230	73.58	1.0	11.31	11.71	0.4	0.4	0.54	
FC-230-40-4	230 ipm/40trim	225	26	11.00	31.91	230	73.58	1.0	11.23	11.58	0.35	0.35	0.48	
FC-275-50-1	275 ipm/50trim	285	29	13.50	36.73	275	87.98	1.0	11.15	11.7	0.55	0.55	0.63	Initial voltage and current settings
FC-275-50-2	275 ipm/50trim	280	31	12.50	41.66	275	87.98	1.0	10.69	11.19	0.5	0.5	0.57	
FC-275-50-3	275 ipm/50trim	295	32	10.00	56.64	275	87.98	1.0	10.25	10.86	0.61	0.61	0.69	
FC-275-50-4	275 ipm/50trim	300	35	13.00	48.46	275	87.98	1.0	9.95	10.62	0.67	0.67	0.76	
FC-275-50-5	275 ipm/50trim	265	27	10.00	42.93	275	87.98	1.0	10.29	10.75	0.46	0.46	0.52	
FC-275-50-6	275 ipm/50trim	260	24	8.00	46.80	275	87.98	1.0	10.64	11.19	0.55	0.55	0.63	
FC-320-60-1	320 ipm/60trim	305	33	13.00	46.45	320	102.37	1.0	11.14	11.83	0.69	0.69	0.67	I Initial voltage and current settings
FC-320-60-2	320 ipm/60trim	308	35	14.00	46.20	320	102.37	1.0	10.92	11.76	0.84	0.84	0.82	
FC-320-60-3	320 ipm/60trim	330	37	17.00	43.09	320	102.37	1.0	9.6	10.37	0.77	0.77	0.75	
FC-320-60-4	320 ipm/60trim	300	31	10.00	55.80	320	102.37	1.0	10.9	11.32	0.42	0.42	0.41	
FC-320-60-5	320 ipm/60trim	295	29	10.00	51.33	320	102.37	1.0	10.4	10.81	0.41	0.41	0.40	
FC-320-60-6	320 ipm/60trim	290	26	9.00	50.27	320	102.37	1.0	10.81	11.41	0.6	0.6	0.59	

Appendix A3 (continued)

Test No.	Program Wire Feed Speed/Trim	Amperage (Amps)	Voltage (V)	Travel Speed (in/min)	Heat Input (Kj)	Wire Feed Speed (in/min)	Wire Wt Used (g)	Time (min)	Filter Beginning Wt (g)	Filter Final Wt (g)	Fume Wt (g)	FGR (g/min)	Percent Fume (%)	Notes
FC-185-30-1	185 ipm/30trim	195	25	11.00	26.59	185	59.18	1.0	11.65	11.83	0.18	0.18	0.30	Initial voltage and current settings
FC-185-30-2	185 ipm/30trim	200	28	11.00	30.55	185	59.18	1.0	11.24	11.46	0.22	0.22	0.37	
FC-185-30-3	185 ipm/30trim	220	30	11.00	36.00	185	59.18	1.0	10.96	11.26	0.3	0.3	0.51	
FC-185-30-4	185 ipm/30trim	230	32	13.00	33.97	185	59.18	1.0	10.09	10.36	0.27	0.27	0.46	
FC-185-30-5	185 ipm/30trim	185	23	8.00	31.91	185	59.18	1.0	10.95	11.3	0.35	0.35	0.59	
FC-185-30-6	185 ipm/30trim	175	21	7.00	31.50	185	59.18	1.0	10.3	10.56	0.26	0.26	0.44	
FC-140-20-1	140 ipm/20trim	160	22	15.00	14.08	140	44.79	1.0	10.39	10.54	0.15	0.15	0.33	Initial voltage and current settings
FC-140-20-2	140 ipm/20trim	155	20	20.00	9.30	140	44.79	1.0	11.02	11.2	0.18	0.18	0.40	
FC-140-20-3	140 ipm/20trim	170	24	12.00	20.40	140	44.79	1.0	11.1	11.22	0.12	0.12	0.27	
FC-140-20-4	140 ipm/20trim	175	26	11.00	24.82	140	44.79	1.0	10.81	11.06	0.25	0.25	0.56	
FC-140-20-5	140 ipm/20trim	180	28	7.00	43.20	140	44.79	1.0	11.28	11.55	0.27	0.27	0.60	

Appendix A4

Miller Invision 456 MP Power Supply, Program 18, Adaptive pulse GMAW, 0.062 inch diameter metal core wire
Miller S-74DX Wire Feeder
75/25 Ar/CO_2 Shielding Gas
Tri-Mark TM-811N2 (E81T1-Ni2H8 filler wire, 0.23 lb/in^3 density, Heat No. S283719-K29

Test No.	Program Wire Feed Speed/Trim	Amperage (Amps)	Voltage (V)	Travel Speed (in/min)	Heat Input (Kj)	Wire Feed Speed (in/min)	Wire Wt Used (g)	Time (min)	Filter Beginning Wt (g)	Filter Final Wt (g)	Fume Wt (g)	FGR (g/min)	Percent Fume (%)	Notes
FC-230-40-1	230 ipm/40trim	205	25	10.00	30.75	230	73.58	1.0	11.35	12.27	0.92	0.92	1.25	
FC-230-40-2	230 ipm/40trim	210	27	12.00	28.35	230	73.58	1.0	10.99	11.64	0.65	0.65	0.88	
FC-230-40-3	230 ipm/40trim	215	30	8.00	48.38	230	73.58	1.0	10.66	11.77	1.11	1.11	1.51	
FC-230-40-4	230 ipm/40trim	220	31	11.00	37.20	230	73.58	1.0	11.13	12.3	1.17	1.17	1.59	Initial voltage and current settings
FC-230-40-5	230 ipm/40trim	225	33	12.00	37.13	230	73.58	1.0	11.28	12.5	1.22	1.22	1.66	
FC-230-40-6	230 ipm/40trim	235	36	13.00	39.05	230	73.58	1.0	9.36	10.62	1.26	1.26	1.71	
FC-275-50-1	275 ipm/50trim	260	33	11.00	46.80	275	87.98	1.0	10.29	11.59	1.3	1.3	1.48	Initial voltage and current settings
FC-275-50-2	275 ipm/50trim	265	36	14.00	40.89	275	87.98	1.0	10.59	12.07	1.48	1.48	1.68	
FC-275-50-3	275 ipm/50trim	270	38	13.00	47.35	275	87.98	1.0	10.64	12.24	1.6	1.6	1.82	
FC-275-50-4	275 ipm/50trim	255	31	11.00	43.12	275	87.98	1.0	10.5	11.67	1.17	1.17	1.33	
FC-275-50-5	275 ipm/50trim	250	29	11.00	39.55	275	87.98	1.0	9.47	10.68	1.21	1.21	1.38	

Appendix A4 (continued)

Test No.	Program Wire Feed Speed/Trim	Amperage (Amps)	Voltage (V)	Travel Speed (in/min)	Heat Input (Kj)	Wire Feed Speed (in/min)	Wire Wt Used (g)	Time (min)	Filter Beginning Wt (g)	Filter Final Wt (g)	Fume Wt (g)	FGR (g/min)	Percent Fume (%)	Notes
FC-320-60-1	200 ipm/40trim	190	26	9.00	32.93	200	63.98	1.0	11.08	11.74	0.66	0.66	1.03	
FC-320-60-2	200 ipm/40trim	220	37	10.00	48.84	200	63.98	1.0	10.61	11.9	1.29	1.29	2.02	
FC-320-60-3	200 ipm/40trim	210	35	12.00	36.75	200	63.98	1.0	10.25	11.18	0.93	0.93	1.45	Initial voltage and current settings
FC-320-60-4	200 ipm/40trim	200	28	8.00	42.00	200	63.98	1.0	9.94	10.68	0.74	0.74	1.16	
FC-320-60-5	200 ipm/40trim	210	32	11.00	36.65	200	63.98	1.0	10.36	11.51	1.15	1.15	1.80	
FC-320-60-6	200 ipm/40trim	205	30	9.50	38.84	200	63.98	1.0	10.81	11.65	0.84	0.84	1.31	
FC-320-60-7	200 ipm/40trim	180	24	8.00	32.40	200	63.98	1.0	9.63	10.07	0.44	0.44	0.69	
FC-185-30-1	185 ipm/30trim	183	28	12.00	25.62	185	59.18	1.0	10.14	10.87	0.73	0.73	1.23	Initial voltage and current settings
FC-185-30-2	185 ipm/30trim	190	30	12.50	27.36	185	59.18	1.0	11.17	11.92	0.75	0.75	1.27	
FC-185-30-3	185 ipm/30trim	195	32	13.00	28.80	185	59.18	1.0	10.66	11.53	0.87	0.87	1.47	
FC-185-30-4	185 ipm/30trim	177	26	10.00	27.61	185	59.18	1.0	10.77	11.5	0.73	0.73	1.23	
FC-185-30-5	185 ipm/30trim	174	24	10.00	25.06	185	59.18	1.0	10.76	11.33	0.57	0.57	0.96	
FC-140-20-1	140 ipm/20trim	150	25	24.00	9.38	140	44.79	1.0	9.03	9.55	0.52	0.52	1.16	Initial voltage and current settings
FC-140-20-2	140 ipm/20trim	145	22	27.00	7.09	140	44.79	1.0	10.17	10.62	0.45	0.45	1.00	
FC-140-20-3	140 ipm/20trim	152	27	19.00	12.96	140	44.79	1.0	11.24	11.89	0.65	0.65	1.45	
FC-140-20-4	140 ipm/20trim	140	20	18.00	9.33	140	44.79	1.0	10.52	10.94	0.42	0.42	0.94	

WELDING PROCEDURE Page 1 of 2

Weld I.D. ANAD-1
Date 10/8/03
Engineer K. Tran
Welder H. Prince
Project ESTCP Welding Project

NSWCCD, Code 615

Equipment/Location Miller 456MP Power Supply, Miller S-74DX Wire Feeder

Process GMAW, Adaptive Pulse Position vertical

Weldment Size: Length 12 inches Width 0.5" face opening

Base Metal Type Mild Steel I.D. Thickness 1"

Backing Material copper bar I.D. Thickness 1/2"

Electrode Type E811T1-Ni2H8 Mfr./Name TRI-MARK

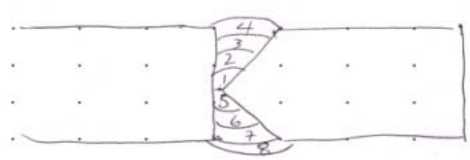
Size 1/16" dia Heat S283719-K29 Lot 656850 1624 Batch

Electrode Handling

Flux? Y / N Mfr/Name Lot/Batch

Shielding Gas? **Y** / N Type Ar/CO2, 75/25 Flow Rate 30 cfh

Joint Design



Preheat Temp none
Interpass Temp 250-300 F
Voltage 24-25
Wire Feed Speed 175
Current 170-180
Travel Speed 4-6 inches per minute
Heat Input 50-100 KJ

Other

Joint Preparation

Inspection RT

Special Requirements Miller 456MP Power Supply, used Program 18, adaptive pulse for 0.062 inch metal core wire. Grinded after each pass prior to depositing next pass

WELDING RECORD

NSWCCD, Code 615

Page 2 of 2

Weld I.D. ANAD-1

Welder H. Prince

Date 10/8/03

Bead	Volts	Wire Feed	Amps	Travel Speed	Heat Input	Weld Time	Inter-pass Temp	Inter-pass Time	Remarks
1	24	175	170	4.5	54	2min 40 s	210		Grind between passes
2	24	175	170	4.4	56	2min 45 s	210	10 min	Grind between passes
3	24.5	175	170	4.8	51	2min 31s	202		Grind between pass
4	24.3	175	175	~3.1	81.5	3min 50 s	202		
5	24.5	175	176	4.2	61.6	2min 50s	215		Grind between pass
6	24.4	175	177	4.4	58.9	2min 45s	220		Grind between pass
7	24.2	175	177	4.5	57	2min 41 s	215	6 min 6 sec	Grind between pass
8	24.4	175	180	2.7	97	4min 31 s	205		
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Appendix K

Example Product Literature and Field Reports